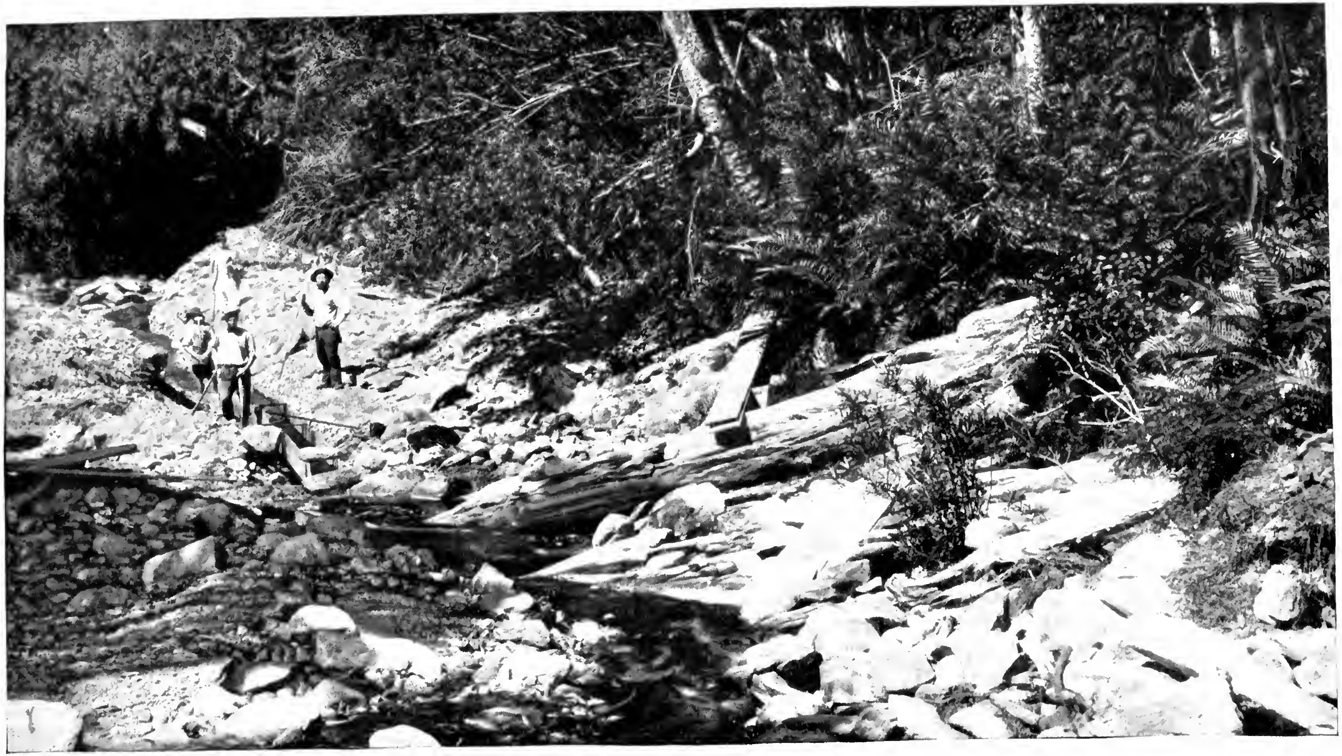
CAUSAL GEOLOGY



GOLD-WASHING, MILLWOOD, KNYSNA, CAPE COLONY

The gravel in the pools is worked over one season, and after a year or two the same pools are found to be as rich as before. The rock is Table Mountain Sandstone; there are a few low-grade quartz reefs and a banket formation up the creek from which the nugget gold is derived, although the gold is never

Frontispiece

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TO

PROFESSOR J. W. JUDD

C.B., LL.D., F.R.S., F.G.S.

IN GRATEFUL REMEMBRANCE

PREFACE

In the ten years spent on the Geological Survey of the Colony of the Cape of Good Hope I was brought into contact with most of the geological problems that are presented by our earth in a way which, I believe, is afforded nowhere else. The whole country, practically, is bare of soil and the rocks lie ready to the hammer everywhere, while the enormous gashes sawn through the land by the rivers reveal sections of unparalleled magnitude and clearness. As year by year went by the facts presented themselves to me in an order different from that stated in the text-books, and the theories as to their origin and nature became simplified and different from established ones. There seemed to me no need to speculate on enigmatical problems, but the facts observed, if allowed to arrange themselves according to their natural sequence, explained many of the problems that are the subject of so much controversy. I feared that in the isolation from centres of current geological thought I had gone off on a side track which led nowhere, but the publication of Professor T. C. Chamberlin's Planetismal Hypothesis [1] showed me that I was travelling in a direction which, at least, was being taken by others. The planetismal hypothesis allows known facts to weigh more than theories, and enables one to build up a system of geology without an appeal to the

[1] T. C. Chamberlin, *Year Book Carnegie Institution, No. 3*, 1905, pp. 208-253; T. C. Chamberlin and R. D. Salisbury, *Geology*, "Earth History," vol. ii. London, 1906, pp. 38-81.

unknown and unknowable. It is not for me to judge the merits of this hypothesis, but in my opinion it is the most positive advance in natural science that has been made for a very long time. But there is more than the planetismal hypothesis; there are the logical consequences of its acceptance, and as far as I know no comprehensive work has appeared dealing with these, though Professor C. R. van Hise's gigantic book on Metamorphism [1] is a storehouse of facts in favour of the hypothesis. The hypothesis must stand or fall on the merits of the consequences of its acceptance, and I have endeavoured in my own way to set these forth. I have not attempted an exhaustive treatise on the subject—indeed, in this distant corner of the world my means are far too limited to accomplish such a task; but I have put together, as far as I have been able to do so, a general statement of the readjustments of our outlook necessitated by this hypothesis. How much of the book owes its matter to the inspiration of the planetismal hypothesis, and how much is my own, I cannot say, but I accept all blame for mistakes in interpretation of the phenomena described. In many cases I have gone much further than Professor Chamberlin, but the object I have set before me is to lay the whole case from the single point of view of a solid earth.

To look at the subject-matter in a different light: I have presented logical deductions from obvious facts, and where they differ from accepted explanations, the fault may lie in my reasoning; but as this has been the result of long and sustained association with geological phenomena in the field, some good may accrue from looking at the problems from a new point of view, even if eventually the interpretations are proved to be incorrect.

[1] C. R. van Hise, "A Treatise on Metamorphism," *U.S. Geological Survey Monographs*, vol. xlvii. Washington, 1904, pp. 1-1286, $30\frac{1}{2} \times 23$ cm.

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CAUSAL GEOLOGY

CHAPTER I

THE EARTH

THE fundamental conception of the earth is that of a solid globe some 8000 miles in diameter. Our faith, however, in this solidity is shaken when we read of the submerged forests of Cromer, or the sunken houses in Lisbon harbour, and, on the other hand, of rings set in the rock, to which Vikings once moored their ships, which are now far inland. There has been movement on the surface of this globe, and not only in one direction vertically, but often, as shown in the marble columns of the temple of Serapis at Pozzuoli, both upwards and downwards at the same spot. To the geologist this is obvious in almost every part of the globe, for he sees vast accumulations of marine sediments converted into dry land, with their included fish-remains and shells and hard parts of the teeming marine organisms, testifying unmistakably as to their origin; he sees these repeatedly separated by breaks or gaps which, from their evidences of river courses, rubble, and soil with roots of trees still present, and similar signs which can be appreciated by the skilled inquirer, indicate intervening land periods.

The rock immediately beneath one's feet is apparently solid, therefore these movements must be ascribed to a liquid substratum or core, on which the outer crust floats. In volcanic regions, whose vents shower forth at intervals incandescent ash and steam with terrific violence and again pour

out from the depths vast floods of molten rock, the proof of the existence of this liquid substratum or core seems perfect. Nevertheless we shall explain all these phenomena and many more which are not so obvious, on the assumption that the earth is solid and cold throughout, and has been so since it began to be formed. We shall not endeavour to inquire in every case why each individual phenomenon cannot be satisfactorily explained on the theory of the liquid interior of the globe, but by clearing away the conception of this hot region beneath our feet we shall show that all the manifestations of geological forces which we can observe can be simply and logically accounted for on the theory of a solid, cold interior.

The First Postulate. The rocks on the surface of the earth are in constant motion.

If we wish to build a house it is of the utmost importance to make sure that the foundations rest on solid rock, and the task of finding this is by no means easy; if it is a big edifice or an extended structure like the retaining wall of a reservoir, the task is rendered all the more difficult, indeed often impossible, and if the true history of most large undertakings of this kind were known, it would become apparent that the engineers have consciously taken risks which would, if they had stated them, have led to the abandonment of the construction. The reason for this is that every portion of the earth is gradually moving; piers for carrying telescopes and transit instruments in observatories, embedded in concrete foundations on the solid rock, have been found to tilt a number of years in one direction, and perhaps sustain a reverse motion subsequently until they again assume the vertical; or it may be one portion of the surface of the earth moves in one direction vertically or horizontally across a definite line, and another portion moves in the reverse direction or remains stationary.

These movements are not the large movements which cause faults and folds—we shall come to these later on—but they are the result of movement in the few hundred feet at the surface of the earth which we can examine exhaustively

for any signs of fluidity, and be convinced that it is perfectly solid. Perhaps the most striking proof of this is the tilting measured in the Oxford University Observatory: when a body of seventy-six men walked up to within twenty feet of the walls, the horizontal pendulum inside showed an appreciable deflection in the direction of the advancing load. Milne gives several other instances. In the Isle of Wight, and the same thing has been observed in Tokio, the sides of a deep valley approach each other towards evening and open out in the morning; the explanation being that during the day the transpiration of the vegetation is constantly removing moisture from the soil, whereas in the night-time this is to a large extent stopped, and the earth is weighted with the accumulating water; this extra load is sufficient to press down the earth, reduce the curvature at that point, and so to cause the valley to narrow. Marked effects are produced on rainy days, and even a cloudy day, when transpiration of the vegetation is small, causes the water to accumulate and press down the earth. On the advance of the tide towards the land the seepage of underground water seawards is stopped and a quantity of water is dammed back behind the shore line; this extra load is sufficient to counterbalance the extra load of the sea-water, and the shore tilts backwards.[1] Sutton, watching the movement of a horizontal pendulum at Kimberley, found that there was a tilt occurring twice daily which was due to the pull of the sun on the earth's surface; in fact a bulge of the earth's crust follows the sun in its course, and this is due to the fact that the load on the earth is relieved by so much as is represented by the attraction of the sun.[2] Long period attractions, due to the shifting of the axis of the earth and similar causes, all leave their mark, and these slight readjustments operating through centuries definitely alter the surface of the earth.

If seventy-six men can tilt a great building like the Oxford University Observatory, which has particularly solid founda-

[1] J. Milne, Bakerian Lecture, *Proc. Roy. Soc.* A. vol. lxxvii. 1906, p. 375.
[2] J. R. Sutton, *Trans. Roy. Soc. S. Africa*, Cape Town, vol. i. 1909, p. 303.

tions; if a fraction of an inch of water spread over the land after a shower will cause an appreciable depression, what will happen if a foot of rock is taken off the entire surface of a continent and deposited on the sea-floor adjacent? The land will rise and the sea-floor will be depressed and the whole segment of the earth's crust will be tilted.

This action is continuously going on. Rivers carry mud and sand derived from the waste of the land and deposit them on the ocean floor near the land, and there is never any cessation of the process; year in, year out, the land is degraded and the sea-bottom near the shore fills up; movement of the earth's crust as a consequence must be continually in progress. This is the first of the primary conceptions with which we shall start on our inquiry into the nature of the earth as a whole. In later chapters the matter will be fully gone into and the consequences, as manifested in geological phenomena, exemplified. The rate of removal and the amount of rock removed; the processes of denudation such as the diurnal expansion and contraction of rocks as heated by the sun's rays by day, and cooled by radiation of heat by night, causing splitting and cracking; the percolation of water dissolving soluble substances; the action of frost, and so on, by which the waste of continents is accomplished, and inch by inch of solid rock is stripped from off them, and transported by rivers, glaciers, and wind to the ocean; all these facts form the subject matter of most geological treatises, and are within the common knowledge of every one. It is sufficient here to establish the fact that there is movement in the earth's crust entirely caused by agencies at work on the surface.

The Second Postulate. The force of cohesion in rocks is insufficient to keep them rigid when in large masses.

How does this movement take place in rock perfectly solid to all appearances? This brings us to the second of the conceptions which will underlie all the reasoning advanced in this book. A block of rock a foot cubic measurement is

solid because its mass is sufficiently small to allow the force of cohesion to act. A block of rock a cubic mile in dimensions is solid only so long as it is supported; if the supports are taken away it in time gradually subsides as a viscid liquid, such as pitch, would do. Experimental proof in the case of most rocks is difficult, but in the case of marble Adams has shown that it readily flows under pressure,[1] while door jambs in the Alhambra and suspended slabs in churches, as mentioned by Sir A. Geikie, have in course of time sagged quite out of their original shape. In marble we have the easy solubility of the carbonate, and the perfect gliding planes in the crystals of calcite to account for the accommodation to pressure; but similar bending of rocks of a more refractory nature is known in deep mines, where the roof caves in when the supports are withdrawn. The reason why the rock flows is subject-matter for a subsequent chapter; all we want here to establish is the fact that it does flow, and that the accommodation to stress is accomplished at temperatures, not only far below the melting point of the rock, but actually at the normal temperature at the surface of the globe.

The differences in the effect of cohesion in small and large masses is forcibly illustrated by Herbert Spencer in the case of the elephant and the flea. If both were to be projected a hundred times their respective lengths the flea would alight unharmed and ready for another hop, whereas the elephant would be smashed to pulp. Similarly if a force be applied to a small block of rock it will remain perfectly rigid, whereas if a proportional force be applied to a block many hundreds of times the size, the rock will not respond as a rigid body. Applying this principle to the great rock we call the earth, the cohesion of the whole is so small when operated upon by long sustained forces that it obeys the laws of liquids. Sudden shocks, such as earthquakes, find the earth perfectly rigid, but the rotational force which acts continuously is sufficient to keep the earth in the shape a liquid sphere would do under

[1] F. D. Adams and J. T. Nicholson, "An Experimental Investigation into the Flow of Marble," *Phil. Trans. Roy. Soc.* cxcv. A. 1901, p. 363.

the same circumstances. Consider what would happen if this were not the case and the globe were permanently rigid. In the lapse of time represented by our geological systems, earth movements have resulted in the folding of mountains, and the accumulations of these upheavals would have distorted the shape out of all recognition. It is the appreciation of this fact that has led many to postulate, apart from any other considerations, that the interior of the earth is liquid from intense heat, and that the crust floats upon it; but the readiness with which cold, solid rock flows in large masses under long sustained forces, sufficiently explains the matter without having recourse to this assumption.

The Third Postulate. The area of the surface of the globe is not a diminishing one.

In the folding of mountains great beds of rock are crumpled, much as layers of carpet would be if the ends were pushed together. In other words, where there is a folded mountain chain there has been contraction in that segment of the earth's crust. In the case of the Alps the contraction has been estimated at seventy-four miles. The older geologists used to liken the earth's crust to the skin of an apple that has dried, showing how the shrinking of the inner core forces the outer rind to wrinkle in order to accommodate itself to the diminished area. In the whole area of the earth's surface, however, where the forces of contraction are everywhere in evidence, from the grand scenic effects of the mountain ranges which have been born of the movement, less conspicuous, but quite as important, compensatory movements have taken place, transferring to the stretched and fissured portions of the crust material, in the form of dykes and sheets of intrusive molten rock, which has been displaced by bulging of the crust in another part. In mountain building, in the case of a simple ∿-shaped fold, the centre of gravity of the whole is maintained at the same level throughout by the rotational force of the earth, which prevents the excessive upthrust of material; consequently as much is thrust downwards into the subcrustal portions of the

earth as is forced up above the surface; the roots of the folds, as Fisher has called them, displace the subcrustal material, and where cracks and fissures occur, caused by the dragging of rock from any district to form the folded mountains, there it is thrust in in the form of dykes. It is impossible to state this quantitatively, owing to the fact that denudation so quickly destroys mountains, and works slowly in the plains beneath; therefore a whole mountain range may disappear before the injected material will be bared to observation. In the case of the Himalayas, a comparatively recent mountain range, Burrard has established by means of pendulum observations that an immense injection of basic material lies under the southern flanks, sufficient to counteract the attraction of the mountains.[1] Further, in the Deccan basic intrusions occur whose bulk would occupy a sphere thirty-six miles in diameter. In South Africa the contraction represented by the folded mountains of the coast is compensated by an injection of dolerite in the interior, reckoned at a minimum of 70,000 cubic miles, or a sphere with a diameter somewhat greater than fifty miles. In the older folds of the Transvaal the contraction is compensated by the vast field of the igneous rocks of Bushveld Plutonic Complex.

The third conception, therefore, which we shall use is that contraction of the earth's crust in one part is compensated by expansion in another, and that in the general average no loss of area has been experienced over the globe as far as we can go back in time. It is admitted that this is a highly contentious point and is rigorously denied by the upholders of the liquid interior theory, but it is forced upon one studying the geology of the earth's crust as a whole. Whether we derive it from our experience, or formulate our theory and deduce it as a natural consequence, it is one of the postulates of the order of reasoning adopted here. If it is wrong then we must abandon our hypothesis of a cold, solid globe.

[1] S. G. Burrard, "On the Intensity and Direction of the Force of Gravity in India," *Proc. Roy. Soc.* lxxvi. ser. A. 1905, p. 313; Osmond Fisher, "Physics of the Earth's Crust," 2nd Ed. 1889, chapter xiv. p. 194.

The Fourth Postulate. The Surface of the Earth is Uniform in average texture throughout.

A further postulate which we shall adopt is that the crust of the earth is uniform in texture throughout the continents and ocean basins, and that the depressions in which the waters of the ocean lie are temporary accidents. This is an extremely difficult point to prove; the evidence afforded by the Cambrian and Silurian sediments in Europe establishes the fact that they were derived from a continent which lay where the North Atlantic now is. Then the folds in the more ancient rocks of Great Britain and North France are repeated on the other side of the Atlantic as if they were part of one great arc, and that the central portion is now foundered beneath the ocean. In the Falkland Islands and South Georgia, and in the Antarctic Islands of the South, the continental rocks of South America are continued into the abyss of the ocean. In the Pacific the islands bordering the great central basin, Japan, New Zealand, New Caledonia are portions of a continent with rocks identical with those forming the surface of other lands, and there must be an extension of such rocks far to the seaward of them. Woolnough, indeed, has shown that the volcanic group of the Fiji Islands stands upon a base of quartzite and gneiss,[1] and Lister has brought forward evidence that the Tonga Islands rest on a similar base.[2]

We cannot assume, as has been done, that the continents are, as it were, islands floating upon a heavy substratum, sustaining them as water sustains icebergs, and that the ocean basins are underlain by heavy material. The contours of our continents present such alluring lineaments for the development of this theory. For instance the crook on the east of South America fits so nicely into the Gulf of Guinea, and the two land masses if pulled together would practically interlock. Yet it must be remembered that

[1] W. G. Woolnough, "The Continental Origin of Fiji," *Proc. Linn. Soc. N.S. Wales*, 1903, vol. xxviii. p. 457.

[2] J. J. Lister, "The Geology of the Tonga Islands," *Quart. Journ. Geol. Soc.* 1891, p. 600.

neither America nor Africa is a land mass built up in one period; there are Archæan ridges forming the backbones, and to these are added concentric shells of newer rocks, each the product of vast lapses of time and separated by periods of earth movement of which we have as yet scarcely any clue. If, then, the lineaments of the two continents are similar where they face each other across the Atlantic, this is a coincidence that has only been brought about recently in the earth's history, geologically speaking, and such a coincidence is not likely to have recurred at any previous stage of development. The theory of the Permanence of Ocean Basins is, then, one which we must abandon, and we must assume that as there is evidence of oceanic conditions in continental areas, so in oceanic areas there must be, if we could see them, evidences of past continental conditions; continents will rise and ocean beds sink according as the accumulation of stress on the outer surface of the earth's crust tends to operate.

The Fifth Postulate. The earth is growing by the addition of meteoric matter, and the composition of the earth as a whole is represented by the average composition of this matter.

Finally, we have to bring to our investigation of the earth as a whole no speculation as to the possible nature of it, but we have to take the facts as presented to us simply and without sophistication.

There fall on to the earth some million meteorites in the twenty-four hours; we cannot look long into a clear sky at night before seeing one or more shooting stars, and another observer a hundred miles distant will see another group of falling stars in the same time, and other observers other meteorites, and so on over the whole globe. As a rule these are too small to reach the earth; they burn, and the powder of their disintegration falls as an impalpable dust to the ground, and we can sweep it up on the surface of snow exposed unmelted and unadded to for years within the Arctic regions, or we may scoop it up from the abysmal depths of the ocean far beyond the reach of solid material

carried from the land. Taking Arrhenius' estimate of the total mass of meteorites falling upon the earth in a year as 20,000 tons, the individual meteorites would average about 9 to the pound; at this rate, in the historic period alone, some two hundred million tons have been added to the earth.

Occasionally the meteorites are large enough to persist in their flight through the atmosphere and they fall warm to the earth. Those that have been observed immediately after their fall are hot and melted on the outside, but the heat developed has never been known to melt the stone right through. If we had to rely on the meteorites at the rate they now fall on to the earth to build up the globe from the commencement, they would make such an insignificant total in a vast lapse of time that we should reject the theory as improbable on that ground alone. The fact remains, however, that the earth is growing even now, although but slowly. The largest that has been discovered is only some fifty tons in weight, and would not appreciably affect the mass of the earth. But there is every reason to believe that from time to time during the earth's history very large bolides have fallen, and not only in past time but in the future also we can expect masses of a million tons and more to drop in. Eros, the so-called dark moon, would be such a mass, and there is every probability that that satellite will be some day added to the earth's possessions. The earth, then, is growing by the addition of material which we can examine, and there is no reason for supposing that there has been any change in the nature of this material falling in from the earliest period of the earth's separate existence.

This meteoric material consists of iron and stone; iron with more or less of nickel alloyed to it, and stone consisting of silicates of magnesia and iron. All grades of admixture of iron and stone are known in meteorites, but our material is too scanty to enable us to arrive at an average of the composition of the falls that occur in a given time, which, could we obtain it, should give the average composition of the globe as a whole.

The density of the earth is 5.5. Taking silica and iron as the chief ingredients, a mixture of four of silica and six of iron would give us a mean density of 5.5. We do not know, however, what happens when material is subjected to the enormous pressures which exist in the central portions of the earth. It may be that the state of the materials is altered, and that their density is increased; if so, then silica would be in a larger proportion, but the proportion of iron meteorites now falling to stony ones is such as to negative this supposition.

This, then, is our last postulate, that the earth is a vast rock composed essentially of iron and silica in the proportion of 6 to 4. As to the rim, estimated at from $\frac{1}{30}$ to $\frac{1}{45}$ of the whole, that is composed of material that has been worked over and over by the processes of weathering and erosion and subsequent deposit, during which the more soluble substances, principally iron and magnesium, have been carried away downwards towards the earth's centre in solution, leaving behind a residue more siliceous than is natural for the average composition of the globe. The density of the crust is 2.75 as against a general average of 5.5. The rocks composing the outer envelope have been kneaded and rolled by long ages of continuous earth movements, and the properties of this belt are entirely different from those of the interior, but there is no need to argue from this that the two are necessarily of a different nature, because by so doing we leave facts behind and enter into the illusionary domain of pure speculation.

With these five leading ideas granted, I shall deal with the problems of the earth in logical sequence. I do not maintain that I have proved them, but they are general conceptions which follow naturally from the investigation of geological phenomena; where current ideas differ from them there has interposed between the fact and the conclusion theories brought in from other sciences or developed within the domain of geology, and these have served as a screen which has blurred the outline of objects. If I can show that

the whole subject-matter of geology becomes simplified, explanations become more comprehensive, and reservations disappear by accepting these postulates, then I shall have shown reason for adopting them; but to prove them as separate theories is a matter which is beyond the scope of this work.

CHAPTER II

THE SOURCE OF THE EARTH'S ROCKS

THE meteorites that fall continually on the earth are of many kinds, although two types, the iron and stony ones, are sufficiently well defined. Among the stony ones we have the following classes:[1]—(*a*) the ACHONDRITES, masses of rock consisting of crystals of augite, bronzite, olivine, anorthite, with a little chromite and troilite (sulphide of iron). (*b*) CHONDRITES consisting of bronzite, olivine, and nickel-iron, with the constituents arranged in rounded masses or chondrules; these sometimes have needles of iron piercing the mass, and are often broken up into angular fragments which have been recemented together. The most remarkable variety of this class are the carbonaceous meteorites of soft friable nature. The carbon exists either as graphite or combined with hydrogen as volatile hydrocarbons, paraffin in fact. In this group should probably be placed the fall of soot which took place at Pietermaai in Curaçoa in the West Indies in the year 1884. Carbon is again found in the iron meteorites from Canyon Diabolo (Coon Butte) and Penkarring (Yundegin) in the form of graphite, cliftonite, and diamond; the extraordinary similarity between stony meteorites and the matrix of the Kimberley diamonds, taken together with the fact that diamonds occur in meteorites, gave rise to the hypothesis that the diamond mines were nothing more nor less than huge meteorites that by their fall had drilled cylindrical holes in the earth. There are too many facts against this theory to make it worth enlarging

[1] Aristides Brezina, "Die Meteoritensammlung des k. k. Hofmuseums." *Annalen des k. k. naturhistorischen Hofmuseums, Vienna*, 1896, p. 238.

upon, but there is some connection between the Kimberley blue and meteorites, some common denominator which we have been unable hitherto to fathom, but which is readily explained on our theory, as we shall see later. (*c*) SIDEROLITES with nickel-iron disseminated through a stony base. (*d*) LITHOSIDERITES with olivine and bronzite granules in a nickel-iron base, often exhibiting internal fracture (Pallasite). (*e*) Finally there are the iron meteorites, the HOLOSIDERITES or meteorites composed almost wholly of alloys of nickel and iron, with sulphides of iron and small amounts of copper, cobalt, chromium, carbon, chlorine, and phosphorus.

To the undoubted meteorites must be added the extraordinary button-shaped bits of glass that are found in Bohemia and Australia called Moldawite, Billitonite, and Australite. F. E. Suess has referred them to the meteorites under the name Tektite since they are free of included water and thus appear to have formed in an atmosphere devoid of moisture. Verbeek described them as ejectamenta from lunar volcanoes. Dunn, however, explains them as the result of great bubbles of volcanic glass blown from the surface of lava columns; these float about by reason of the hot vapour enclosed until they burst, and the little solid drop of glass at the bottom thus is set free and falls to the earth. They have been seen to fall at Halle and at Igast in Livonia, and their extra-terrestrial origin is at least possible.[1] The point of interest, however, about them is that if we are to ascribe them to meteorites, then we must widen our outlook on the whole question, for moldawite contains from 78-82 per cent of silica and is therefore an acid rock. Hitherto all the meteoric stones have belonged to the ultra-basic series with a percentage of silica of 40 per cent; this has almost been the only criterion for establishing the meteoric nature of the stones in the Achondrite group at any rate, where the outer melted rind has disappeared; if, then, igneous rocks of all types can fall to the ground from the sky we hardly know where to

[1] Aristides Brezina, "Über Tektite von beobachteten Fall," *Anzeiger d. k. Akad. d. Wiss. Vienna*, 1904, p. 41; J. B. Scrivenor, "Obsidianites of the Malay Peninsula," *Geological Mag.* Dec. 5, vol. vi. 1909, p. 411.

stop. The matter is made the more difficult as we have seen many undoubted meteorites show evidences of movement in the mass such as occurs when rocks are caught in the press of earth movements on the globe.

Isolated blocks of igneous origin are known from many parts of the world. In England large boulders of granite have been found embedded in the chalk, but in this case the transport by ice is so satisfactory an explanation that no good can accrue from rediscussing the question. It is otherwise, however, with a block of basalt found in the Cretaceous rocks in the south of Cape Colony.

The occurrence is at the top of the Spiegel River valley in Riversdale, and the rock is peculiar in having abundant plates of very fresh melilite distributed through it. The outcrop is about 100 feet in an east and west direction and half as much across, though, as it is found at the top of a hill and the sides are strewn with debris from it, it is hard to estimate the actual size. There are bands of harder and softer material in it which give the mass the appearance of being bedded, and the dip is some 15° to the south-east. It is surrounded on all sides by soft, loose conglomerates which show no disturbance whatever. Had the mass come up in a volcanic throat one would have expected there to be some evidence of the disruptive force of the explosions in the loose gravel, or some lateral dykes or fume vents, but nothing of the kind could be found, and no other volcanic rocks occur within many miles. The view adopted by the Geological Survey of the Cape is that it is a volcanic vent filled in, but that is because no similar blocks have been described with which to compare it, whereas melilite-basalt occurs in volcanic pipes in the north of Cape Colony. The silica percentage is 36.15 per cent; that of water 2.32 per cent, which would at once throw doubt on the theory that the rock belonged to the class of meteorites did we not remember that the rock is porous and lies under the mountains where the precipitation of rain is very heavy, so that the water may have been taken up subsequently to its fall, if meteorite it be. Many stony

meteorites contain as much or more water, derived doubtlessly in the same way after their fall.[1]

This point, however, is not essential; it is only necessary not to shut out from consideration any rocks which, from their anomalous position, could have fallen as meteorites. One fact stands out, however, namely that meteoric matter is predominantly ultra-basic. With undoubted rocks of extra-terrestrial origin we have sufficient to build up our argument without bringing to our help basic or acid rocks.

The meteorites may be taken to belong to the solar system, but the disruption of Biela's comet shows that similar matter exists outside. Biela's comet, discovered in 1826, was first brought into prominence by Damoiseau, who predicted that it would fall on to the earth on the 29th October, 1832; the comet was where Damoiseau said it would be, but the earth only reached that point in space a month later, so the catastrophe was averted. In 1845 Encke found that the comet had divided into two and in 1852 Secchi saw it again, but much smaller, and the two halves widely separated; since then it has never been seen, but in 1872 and in 1885 when the earth's path cut that of the comet, enormous displays of shooting stars were observed. In 1872 this shower was observed all over Europe. In Italy as many as 38,500 shooting stars were seen to fall in one night, and less numbers in France and England, but still the whole sky was ablaze as in a firework display. The shower was seen by observers in as far distant points as Madagascar, and Bloomington (Indiana) in America, who of course saw other stars than those observed in Europe. Secchi and Lemoisy in Mâcon in France both saw fire-balls, the latter noticed one fall behind a house, but the stone was not discovered. In 1885 a similar display was observed. Rates of fall are recorded from such places as Marseilles (4000 in ten minutes), Brussels (160 a minute), Jena, Madrid (50 a minute) Liége, Prague (14,000 in all), Algiers, Suez (where

[1] A. W. Rogers and E. H. L. Schwarz, "Report on the Southern Districts between Breede River and George," *Third Ann. Rept. Geol. Comm.* 1898, Cape Town, 1900, p. 62.

M. Borghetti described the fall as like that of snow), Athens, Smyrna, and Jerusalem. In Africa the full beauty of the fall was observed in the island of Reunion ; M. Dubuisson records that the people there believed that there could not be any stars left in heaven after such a prodigious shower. In America the shower was observed at Nogalis in Arizona (110 in twenty minutes), Caracas in Venezuela, and Zacatecas in Mexico. At the last place Bonilla counted 2720 in nine hours. In the same shower, at a farm in Concepcion 13 kilometres east of Mazapil, Bonilla records the fall of a meteorite. The proprietor states that it fell with a noise like that of a hot iron suddenly thrust into water ; the men about the farm would not go near it for fear of explosion, but next day they went to the place and found a block of iron, still hot, embedded 30 centimetres in the earth. It weighed 3.9 kilogrammes and was of a quite normal Holosiderite (octahedrite).[1]

It is impossible to estimate the total mass of material received by the earth from Biela's comet, but it must certainly have been considerable, and would have been far greater had the contact occurred before the comet split into two.

What has been stated relative to Biela's comet is true of Temple's comet of 1866 and the comet of 1861, which gave rise to showers known respectively as the Leonids or November meteors, and the Lyraids or April meteors, so it becomes a question whether all our present meteoric falls may not be due to the earth passing through the track of a train of meteoric material. We certainly know that these clusters often assume enormous dimensions ; they occasionally cross each other in space, and by the collisions of the trains of stones give rise to new stars, as in the case of Nova Persei, which suddenly appeared in the sky on February 22, 1901 and in two days passed from a star of the third to one of first magnitude.

Meteorites enter the earth's atmosphere and begin to

[1] J. A. Y. Bonilla, "Über den Fall des Meteoreisens von Mazapil," *Annalen des k. k. naturhistorischen Hofmuseums, Vienna*, Bd. x. 1896, p. 308.

burn at a height of 74 miles with an average path of 42 miles. They enter the atmosphere with a velocity of about 19 miles per second, but they hit the earth from behind, and they therefore have to overtake the earth which is travelling at about the same rate, 18.5 miles per second, therefore they must be travelling at from 35 to 50 miles per second. In two seconds, the individual meteorite is burnt up and disappears, therefore the vast majority must be of very small size. The larger ones invariably explode after a while and scatter into myriads of fragments. Thus in the fall at Knyahinya in Hungary, on June 9, 1866, a thousand or more stones fell, covering an area of some 10 miles by 4, and the largest block weighed 6 cwts. At L'Aigle in Normandy on April 26, 1803, two thousand stones fell over an area 9 miles by 6, many of which were recovered hot, and one struck and burnt the arm of a man.

The largest meteorite known is that of El Ranchito, which was found in 1871 5 kilometres south-east of Bacubirito in Mexico, which is 13 feet long and is estimated by Castillo to weigh 50 tons; but larger ones have certainly fallen. The Anighita meteorite from Cape York, Greenland, weighs 38 tons, while four other Mexican meteorites, namely the Chupaderos, San Gregorio, Concepcion, and Rio Florida, all from the district of Chihuahua, weigh respectively 16, 11, 3, and 3 tons, or 33 tons in all. Arrhenius estimates the total average mass of meteorites which fall in a year at 20,000 tons.[1]

In the Coon Butte, Arizona, there is a crater which was described by Gilbert as volcanic, but subsequent investigation has failed to discover any volcanic material connected with it; on the other hand, strewn round it are masses of meteoric iron of which some 10 tons have been carried away at different times, and now figure in collections as portions of the Canyon Diabolo meteorite. The rocks in the vicinity of the Coon Mountain consist of horizontal beds of Aubrey limestone and sandstone belonging

[1] Svante Arrhenius, "Die physikalischen Grundlagen der Kohlensäurentheorie der Klimaveränderungen," *Centralblatt f. Min., Geol. u. Paläont.* 1909, No. 16, p. 488.

to the Upper Carboniferous series. The mountain is formed by the upturned edges of the strata making a jagged circular ridge, varying in height from 120 to 130 feet above the plain. The chasm is 600 feet deep and 3800 feet across. The nearest lava flows and cinder cones are 12 miles distant, while the San Francisco mountains, which contain many volcanic cones, are 45 miles away. The material at the bottom of the crater has been investigated by Messrs. Barringer and Tilgham by means of bore-holes down to 1000 feet, and the rock encountered is mostly pure white silica which in some places is in the form of impalpable powder; scattered throughout this there are masses of varying size of pumiceous and more compact material, which chemical and microscopic examination show to have been formed by the crushing and fusing of the quartz sandstone. Below the zone of crushed and fused material there is an underlying sandstone quite intact and unaltered.[1] There seems to be no reasonable doubt that this crater is actually the result of the impact of a huge bolide, and the absence of the meteor itself is explained by supposing that the heat of the impact was sufficient to melt and perhaps vaporise its substance, or more probably to cause explosive expansion of the occluded gases which scattered the meteorite as fragments; certainly there is a large quantity of magnetic iron oxide lying as dust about the neighbouring country, which, on analysis, gives a notable percentage of nickel.

If we turn to the moon, whose surface, being free from erosion and deposit, should show clearly any marks made on it by the fall of meteorites, we find certain evidence which is highly suggestive. The craters which lie scattered so freely over the moon's surface were thought by Gilbert[2] to be due to the impact of meteors; that they are not so formed we gather from the following considerations. In some of the

[1] D. M. Barringer, "Coon Mountain and its Crater (Arizona)," *Philadelphia Acad. Nat. Sci. Proc.* vol. lvii. 1906, p. 861; B. C. Tilgham, *ib.* p. 887; G. P. Merrill, *Smithsonian Miscellaneous Collections*, Quarterly Issue, vol. l. 1907, pp. 203 and 461.

[2] G. K. Gilbert, *Bull. Phil. Soc. Washington*, vol. xii. p. 241.

craters the floor stands many hundreds of feet below the general level of the surface, but in others the floor is as much above that level. The internal walls of the craters show definite terraces, like old strand lines, which have been formed by the successive retreat of molten material within the volcanic chimney. The craters, especially the smaller ones, often lie upon definite lines of fissures like the volcanic fissures of Iceland, an arrangement which would have been impossible had they been formed by the infalling of meteors. Lastly there is a regular scale of dimensions corresponding with antiquity in the craters, the larger being the older and the smaller ones successively younger; this we can establish both from the fact that the smaller ones often breach the larger ones, as well as from the freshness of the rocks about the smaller ones as compared with those surrounding the larger ones; for although there is no atmospheric weathering on the moon, the alternate heating and cooling of the surface brings about a certain amount of alteration which in time produces sufficient effect to be clearly noticed through the great telescopes.

These craters do not belong to volcanoes such as exist in the earth, but resemble rather the outbursts of entangled molten matter during the final consolidation of the moon, according to Prof. T. C. Chamberlin's view,[1] and on such a theory the gradation in size is well accounted for. But after this stage was over, when the forces which brought the molten material from the interior to the surface had become spent, no matter what their actual nature was, then the surface of the moon was deluged with floods of lava, which, over tracts many hundreds and thousands of square miles in area, obliterated all pre-existing features, and in their margins invaded and ruined the craters which stood in the path of the molten liquid. These *maria* or dark patches on the moon occupy roughly one-third of the visible portion, as Prof. N. S. Shaler has described in the magnificent memoir on the comparison of the surface of the earth and the moon in

[1] T. C. Chamberlin and R. D. Salisbury, *Geology*, "Earth History," vol. ii.

the *Smithsonian Contributions to Knowledge.* When seen through the great telescopes which bring the moon's surface to within 40 miles of the observer, the margins of the *maria* show that the material of which they are composed flowed in upon the rough ground as very liquid lava would do. It fills in the lower ground forming numerous bays, and in many instances, as is the case of the crater Doppelmeyer, it distinctly appears to have melted down the side of the crater wall next to it and to have filled in the cavity to its own level. This feature is not confined to any one spot or *mare*, but is to be noticed throughout the several thousand miles of the extent of the margins, and leads one to the conclusion that the *maria* were formed by a once fluid matter, as of the sea inundating firm land. The quantity of igneous matter was very great, and in each *mare* or sea it seems to have appeared all at once, there being no mark of successive flows such as compose the extensive lava-fields of the earth. The lava of the several *maria* never overlap, although the gravitative attraction on the moon being only one-sixth of what it is on earth, would allow very steep slopes at the front of even fluid lava flows. The origin of this lava is still hypothetical, but it is to be noticed that none of the volcanoes of the moon give forth freely flowing streams of lava, nor do any of the numerous fissures or faults on the lunar surface, some of which evidently penetrate deeply, distinctly give rise to lava flows; generally it is established that all the volcano-like openings appear always to have retained their lavas within or near their walls, or, in other words, there was no tendency for lava to pass up to the surface in large quantities.

There is no evidence in any of the *maria* that the lava came up from a central pipe or from an elongate fissure; the general form of the seas is rounded or oval, and it would seem to indicate that if the fluid came from the moon's interior the lava should have emerged as from a terrestrial volcanic pipe, for if it came from fissures these should have been of elongate shape. But if the lava came either from fissured or from

pipe-like openings there should be a grade to the flow extending from the centre of the field to its margin; owing to the slight value of gravitation this grade should be steep. There, however, is no trace of such a slope; on the contrary, the curve of the margin of illumination shows the surfaces of the *maria* are essentially horizontal.

The hypothesis which fulfils most of the conditions of the case with respect to the origin of the lava of these *maria* in the moon, is that great meteors fell upon the moon, and by their impact produced sufficient heat not only to melt up their own substance but a good deal of that comprising the adjacent lunar surface. Even beyond the seat of impact the shearing strains would probably be sufficient to convert much of the material of the surface into a fluid state, with the result that a mass of lava at a very high temperature, equal at least to the bulk of the invading body, and probably several times as great, would be sent radially from the point where the impact took place. The evidence of melting effected by the material which forms the plains of the *maria* is considerable at several points, notably in the case of the craters on the margins of the seas. It seems quite certain that the walls of these craters next the sea have been in some manner effaced by contact with the material which came against it; in the case of the crater Flamsteed in the *Oceanus Procellarum* the crater wall has been almost melted down, but still rises slightly above the surface of the inundation. At many points the material forming the *mare* comes against extended steep-faced cliffs, which have the same general character as the inner slopes of the great craters where the form of the declivity certainly has been determined by the melting action of the lava of the base. Further, where there are depressions in the area on the borders of the *maria*, the material of which the floors are composed flows into them as a fluid would have done.

The great objection to the hypothesis that the *maria* were formed by molten rock produced by the impact of large bodies falling upon the surface of the moon, is that similar

A

B

FIG. 1. FEATURES ON THE SURFACE OF THE MOON (N. S. Shaler)

A. *Mare Serenitatis*, showing on the right the great crater Posidonius, and, just below it, that of Le Monnier, with the crater wall facing the *Mare* melted down.

B. *Mare Tranquillitatis*, with *Mare Serenitatis* in the upper portion; the splash of lava is well seen in the upper left-hand corner. In the central left margin a very large crater is seen with its margins all but melted away and a row of smaller craters occupying its borders on the left. In the right upper portion a similar crater ring with half-obliterated borders and smaller craters rising from within it is seen.

To face page 22

bodies, competent to generate a great deal of heat, have not fallen upon the earth's surface in the time which has elapsed since the beginning of the geological periods ; there is so far, indeed, no recorded geological reason for supposing that they have ever fallen upon the planet, but it is just such evidence which I wish to submit. It must, however, be remembered that the moon's surface took its shape long before the beginning of our geological record, so that if such evidence is to be found on the earth, such lavas of extra-terrestrial origin must lie among Archæan rocks, where the unravelling of the tale would be extremely difficult, or they would be entirely hidden under superincumbent strata. It is to be noted also that even in the present stage of the evolution of our solar system there remain bodies in order of size such as would, in falling upon the surface of the larger spheres, produce the effect which we observe in the *maria*. Thus the group of asteroids between Mars and Jupiter, though generally of far greater mass than would be required by impact to melt the larger of the *mare* fields, probably contains many bodies which, in case of collision with our satellite, would bring about the consequences which have been noted. At least one such mass of matter, Eros, has recently been discovered at no great distance from the earth. It is also probable that in a former state of the solar system, when the moon was assuming its present surface features, these detached masses of matter were more abundant than they are at present. The tendency would be for those near the greater spheres to be drawn in upon them, with the result that they would become rarer near the planets and the larger satellites.[1]

Having, then, established the fact that giant meteors may have fallen on the earth and may have melted up tracts of country which would be deluged with lava without apparent vent or orifice from the interior, we can legitimately inquire whether there are any evidences of such occurrences on the earth's surface? There are many vast tracts of lava known

[1] N. S. Shaler, "A Comparison of the Features of the Earth and the Moon," *Smithsonian Contributions to Knowledge*, xxxiv. No. 1438, Washington, 1903.

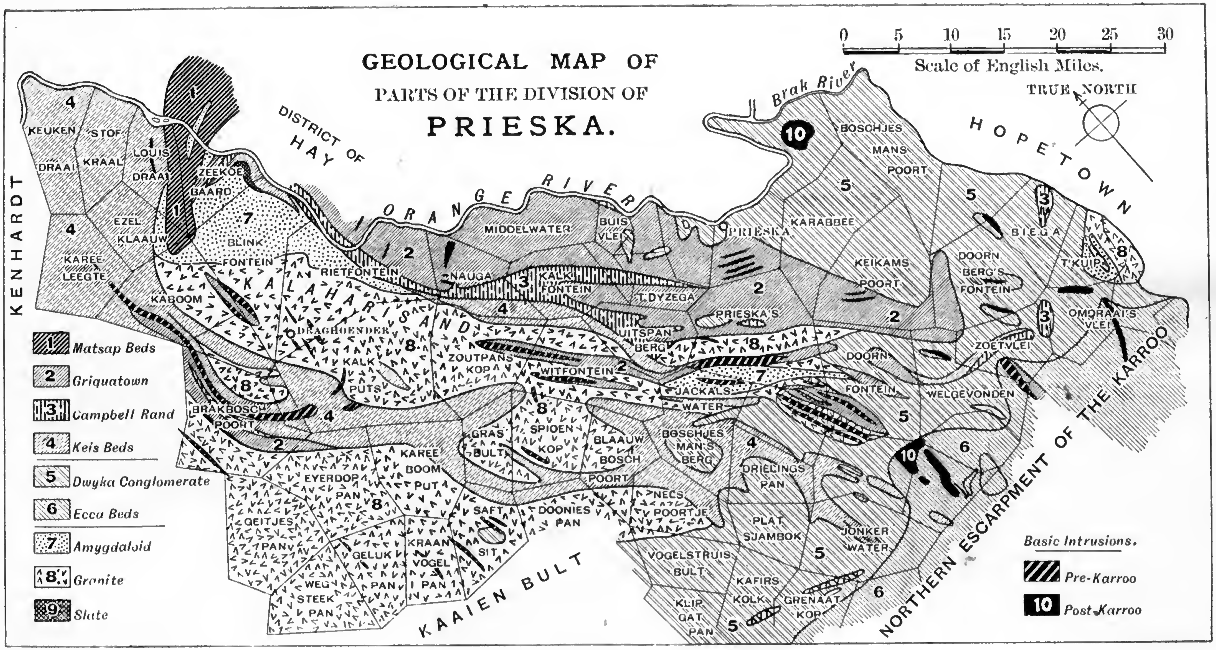
GEOLOGICAL MAP OF
PARTS OF THE DIVISION OF
PRIESKA.
0 5 10 15 20 25 30
Scale of English Miles.
TRUE NORTH
DISTRICT OF HAY
HOPETOWN
KENHARDT
ORANGE RIVER
Brak River
KALAHARI SAND
KAAIEN BULT
NORTHERN ESCARPMENT OF THE KARROO
KEUKEN DRAAI
STOF KRAAL
LOUIS DRAAI
ZEEKOE BAARD
EZEL KLAAUW
KAREE LEEGTE
KABOOM
BLINK FONTEIN
RIETFONTEIN
DRAGHOENDER
KALK PUTS
BRAKBOSCH POORT
MIDDELWATER
NAUGA
KALK FONTEIN
BUIS VLEI
T. DYZEGA
UITSPAN BERG
ZOUTPANS KOP
WITFONTEIN
PRIESKA
PRIESKA'S
KARABBEE
BOSCHJES MANS POORT
KEIKAMS POORT
DOORN FONTEIN
JACKALS WATER
BOSCHJES MAN'S BERG
GRAS BULT
SPIOEN KOP
BLAAUW BOSCH
POORT
KAREE BOOM
PUT
EYERDOP PAN
GEITJES PAN
GELUK
WEG STEEK PAN
KRAAN VOGEL PAN
SAFT SIT
DOONIES PAN
NECS POORTJE
DRIELINGS PAN
PLAT SJAMBOK
VOGELSTRUIS BULT
KLIP GAT PAN
KAFIRS KOLK
GRENAAT KOP
JONKER WATER
WELGEVONDEN
ZOETVLEI
DOORN BERG'S FONTEIN
BIEGA
T'KUIP
OMDRAAI'S VLEI
1 Matsap Beds
2 Griquatown
3 Campbell Rand
4 Keis Beds
5 Dwyka Conglomerate
6 Ecca Beds
7 Amygdaloid
8 Granite
9 Slate
Basic Intrusions.
Pre-Karroo
10 Post-Karroo

Fig. 2.

on the earth which often, if looked at in this new light, may prove eventually to have been formed by the infalling of bolides and not from intratelluric sources. For instance the tuffs, lavas, and agglomerates in the Archæan and Cambrian of Britain, the great lava sheets of the Snake River in Idaho, and the Kapte Plains of British East Africa; even the occurrence on these of small cinder cones and beds of ash and tuff does not necessarily prove that the material came from the interior of the earth, any more than the small blister cones on a flow of molten iron proves that the subjacent floor is riddled with blow-holes.

In the district of Prieska, south of the Orange River, in Cape Colony, there is a tract of country which has been cleared of its covering of glacial drift and stands to-day with many of the features which it presented in a remote geological period. The glacial drift is of Permian age, and the topography revealed with astonishing freshness, belongs to that or earlier epochs. The area was described by Dr. Rogers and myself in 1899,[1] and consists of a base of granite on which rest the various formations of the Transvaal system, quartzites, dolomites, and banded jaspers, and the Matsap or Waterberg sandstone unconformably above these. The rocks present a bewildering number of correlation difficulties, and nearly all the low-lying ground is covered with the red Kalahari sand which obscures the junctions of the several systems of rocks. There are no rivers or stream beds with the exception of the Orange River, and all the water precipitated in the rare rains sinks through the sand and evaporates slowly, leaving behind a crust of calcareous tufa. Weathering, therefore, is of the desert type, and the breaking down of the rocks is nearly entirely brought about by expansion and contraction, without chemical change of the constituent minerals. For this reason the less compact Permian and Triassic clays and shales of the Dwyka and Ecca Series have yielded easily to the forces of destruction and have been blown away; the underlying rocks,

[1] *Ann. Rept. Geol. Comm.* 1899, Cape Town, 1900; see also E. H. L. Schwarz, "The Transvaal Formation in Prieska, Cape Colony," *Trans. Geol. Soc. S. Africa*, Johannesburg, vol. xviii. 1905, p. 88.

however, of dense crystalline structure or of compact metamorphic nature, have emerged with relatively slight alteration from their burial beneath the Karroo rocks. The younger rocks were invaded by dolerite intrusions belonging to the great system of dykes and sills that extends right across South Africa almost from sea to sea, but the older are penetrated by a number of dykes of the most varying types, which have been altered by crushing and metamorphic action generally, so that they can now be described as diabases, granulites, hornblende schists, and serpentine with chrysotile. Besides these last there is a third class of intrusive rock which is, paradoxically, amygdaloidal.

These amygdaloidal melaphyres are known throughout the region of the Pal-afric rocks, whether we trace them on the surface in the Colony, Bechuanaland, or the Transvaal, or encounter them in the depth in the mines of Kimberley. The main group of them occurs below the first member of the Transvaal formation, the Black Reef series, and was called by Molengraaff the Vaal River Beds, and is now more generally known as the Ventersdorp Beds. They consist of lavas of varying basicity, ranging from melaphyres to felsites and rhyolites, and are usually accompanied by enormous developments of agglomerate, ranging from coarse boulder beds to fine volcanic ash.

Two areas of these amygdaloidal melaphyres occur in the Prieska district under discussion, while other and smaller areas are to be found in the neighbourhood. The largest of the masses is found to the north of the district on the farm Zeekoe Baard; it wraps round the end of a range of hills called the Ezel Rand, composed of Matsap (Waterberg) sandstone, and separates these rocks from the granite to the west, and partially interposes between them and the Keis or Black Reef quartzites. There is a small mass also lying apparently intruded in the Waterberg sandstone. On the south side of the Ezel Rand there are some steeply inclined beds of limestone and quartzite, which look as if they were the basal beds of the great limestone series turned up by force from the

direction of the centre of the diabase mass. Towards the point of the Ezel Rand there are tracts of agglomerate which probably belong to the melaphyre. The southern extremity of the melaphyre is on the farm Geelbeck's Dam, where it tapers out; the greatest width of the mass is on the farm Blink Fontein where it is 9 miles across, and the extreme length is 30 miles. A large portion of the area mapped in as melaphyre, is, however, covered densely with red sand, through which the rock only crops out occasionally; on Schalk's Puts (Riet Fontein) and on the eastern part of Blink Fontein there are conspicuous ranges of kopjes formed of the rock.

The melaphyre is in contact with the Keis (Black Reef) series of the farms Ezel Klauw and Louis Draai on the north, and with the Matsap (Waterberg) beds of the Ezel Rand, which it surrounds on three sides. To the south it is bounded by the Campbell Rand (dolomite) series on the one side and the granite on the other. The field-relationships are not compatible with the supposition that the origin of the melaphyre was volcanic, unless a group of faults is brought in to explain the contact of the amygdaloid with such a large range of rocks of widely separated ages; there is no evidence of such faulting, and although the rock is a typical lava, fine-grained to glassy in structure, and generally full of steam cavities, Dr. Rogers and myself were forced to the conclusion that the rock was an intrusive one, and came into position after the earth movements affecting the Matsap Beds had taken place.

About 30 miles in a south-easterly direction, reckoning from the southern extremity of the Zeekoe Baard mass, there is a second outcrop of amygdaloidal melaphyre on the eastern portion of the farm Jackal's Water, and on the western part of the farm Prieska's Poort. The outcrop is elongated about 6 miles and is 1½ miles wide, trending north-west, the direction of strike of most of the Pal-afric rocks in the Prieska district. On the north-eastern side the melaphyre is bounded by the granite of Prieska's Poort, and on the south-eastern

side by the Keis quartzites on the farms Jackal's Water and Uitzigt.

Similar rocks in the neighbouring districts which appear most certainly to be intrusive, have strengthened the view that the Zeekoe Baard and Prieska's Poort amygdaloids are intrusive, but against this we have the steam-holes and agglomerates, clear indications of volcanic origin.

If we accept the volcanic origin, then we must imagine that from a central vent or fissure some extremely fluid lava was poured out, which flooded all the low-lying country, wrapped round the hills, and finally cooled as a plain of lava. No known volcano fulfils these conditions, and from what we know of lava flows we would be inclined to state that such a mass could not be suddenly ejected at any one time, but would rather come up in separate flows, each of which would travel outwards and downwards, and would cool long before it could wrap round the edge of a range of hills such as the Ezel Rand in the manner of a perfectly liquid substance. Then, again, we find the agglomerate at the periphery of the Zeekoe Baard mass, and here also to the north there is evidence of thrust.

In whatever light we look upon these Prieska outcrops of amygdaloidal lava, confining our ideas to a terrestrial origin of the material, we come upon insuperable difficulties, but directly we admit the possibility of the fall of a meteor sufficiently large to melt up a portion of the earth's crust all these difficulties vanish. The sudden development of a large quantity of liquid lava, the permeation throughout of steam-holes from water contained in the rocks melted, the ridging up of portions of the periphery of the mass, the absence of true volcanic ash but the great development of crushed up material entangled in molten rock—all these phenomena receive an adequate explanation on the meteor hypothesis. That the masses of lava often tail out into apparent dykes can be readily accounted for from the fact that earth movements have gone on since the development of the lava, and such dyke-like extensions would be portions drawn out

by crushing, just as a crystal of felspar is drawn out in many gneisses.

Against the general acceptance of such a theory there is the objection that certain of the Archæan and early palæozoic periods are characterized by just such volcanic rocks as are to be found in Prieska, great masses of lava and clastic igneous rocks of all sorts. If any of such volcanic areas owe their rocks to meteors, it is certainly probable that the masses of planetary matter were grouped in swarms which would produce the same effect on the whole as a general outburst of great volcanoes over the earth. Each swarm would gradually discharge the individual bolides as the earth in its course round the sun came within attracting distance, and when the swarm was exhausted or passed out of reach of the earth's attraction, then there would be a cessation of the production of these igneous rocks, and normal sedimentation would take place.

The evidence, then, is highly suggestive that the earth has grown and is growing from the infall of large meteorites; the rate of growth at present is very slow, only 20,000 tons a year, whereas the earth as a whole weighs about 6×10^{21} tons. Arguing from known facts we must assume that at one time there was sufficient meteoric material available to enable the earth to grow up far more rapidly than at present, and we shall now proceed to inquire whether there is a theoretical justification for such an assumption.

CHAPTER III

THE BUILDING OF THE EARTH

WITH an unlimited number of meteorites falling as they now do without fusion, and with time such as we consider it geologically, we can build up a solid earth without any difficulty. The fact that we have not had any very great infalling of meteoric matter during the time represented by the historic period has led scientific men to seek the origin of the earth in other ways, the most generally known theory being the Kant-Laplace or Nebular Hypothesis, or the Meteoric Hypothesis of Lockyer as modified by Darwin to include the Nebular Hypothesis.[1] The impact of a very large mass, however, would probably cause such a shock to the earth that all the higher organisms would be destroyed, something after the manner in which the fish off the coast of South Africa were killed by the shock of the Krakatoa earthquake; that men have lived through the historic period is then due to the immunity of the earth from such visitants during that period, but 10,000 years or so are but a moment in geological time.

Although we may build up our earth out of meteorites and find that all terrestrial phenomena follow naturally from such an assumption, we still have to explain the relation of the earth to the sun and the other planets, and it is to this end that the presentment of Chamberlin's original statement of the planetismal hypothesis is directed. The astronomical minutiæ need not detain us here as they are set forth in full

[1] Sir J. Norman Lockyer, *The Meteoric Hypothesis*, 1890; G. H. Darwin, "On the Mechanical Conditions of a swarm of Meteorites and on the Theories of Cosmogony," *Phil. Trans. Roy. Soc.* clxxx. 1889, p. 1.

in Chamberlin and Salisbury's *Geology*, and the mathematical side is dealt with by Moulton.[1]

The central fact of the theory is that we have in the sky some 1000 million suns, moving each with terrific velocity in different directions; besides these luminous bodies there are dark suns, sometimes joined with luminous ones in binary stars, but others moving about as independent units. To each of these suns there are probably allotted a system of planets and satellites, making up all together a prodigious total.

These stars do not have infinite space to move about in, but are confined to a definite cluster. If we take a survey of the sky in the northern or southern hemisphere with unaided eyesight, we shall be able to count a certain number of stars. If we use an opera glass we shall see more; with a telescope of low power still more, and so on as we increase the power of our telescope. Each stage of visual power indicates a range of so many units of distance, and for equal distances the stars ought to be aggregated with equal averages; that is to say, if we number off successive shells of space as No. 1, 2, 3, and so on, an equal area in each of the shells should contain an equal number of stars. This is true for the lower powers of the telescope, but with the very largest instruments the numbers in the outside shells diminish; that means that the stars are becoming thinner, and in between them we see some of the starless space beyond. The old view that had we telescopes strong enough we should see a continuous canopy of light derived from the stars, has, therefore, no foundation.

Dr. Alex. W. Roberts of Lovedale, has kindly given me a more precise statement of the above facts. If the universe be infinite we may conceive the stars to occupy concentric shells. Gould in his investigation on this principle found the following formula for the number of stars in shells of various magnitude.

$$\Sigma_m = 1.05(3.91)^m.$$

[1] T. C. Chamberlin, *Year Book, No. 3, Carnegie Institution*, 1905, p. 208; T. C. Chamberlin and R. D. Salisbury, *Geology*, vol. ii. "Earth History," 1906, p. 38; F. R. Moulton, *Astronomy*, 1907.

Where Σ_m is the total number of stars seen from the earth up to a certain magnitude, m. Dr. Roberts finds for the southern stars

$$\Sigma_m = 1.00(3.91)^m.$$

This principle works out correctly up to stars of the ninth magnitude. Thus up to magnitude 9 we have

$$\begin{array}{rl} \Sigma_m = & \log 1.00 = 0.0000 \\ & +9 \log 3.91 = 5.3298 \\ \hline & 5.3298 = 342{,}000 \text{ stars.} \end{array}$$

Up to magnitude 15 we have

$$\begin{array}{rl} \Sigma_m = & \log 1.00 = 0.0000 \\ & +15 \log 3.91 = 8.8830 \\ \hline & 8.8830 = 764{,}000{,}000 \text{ stars,} \end{array}$$

which is certainly far above the number actually registered. When we move up to higher magnitudes, say the twentieth, the disparity between observation and theory becomes grotesque. Kapteyn entered upon an inquiry as to whether light was not lost on its passage through space, and corrected the formula to $\Sigma_m = p\ (q)^m$ on this supposition. He came to the conclusion that light was not lost in its passage through space, but that the stars were actually thinned out.

From prolonged observations and measurements Kapteyn has shown that not only is the sun moving definitely towards a certain spot in the stellar cluster at a rate of about 12 miles a second, but that all the stars are moving, and in opposite directions;[1] more recently Boss has shown that there are many streams of stars in the sky moving in all directions.[2] With restricted area in which to move the stars must from time to time approach each other. If two stars are both rushing directly towards the same spot in space, then there will be a collision and the impact will convert the two into a gaseous incandescent mass.

It is with such a mass that the Kant-Laplace theory

[1] J. C. Kapteyn, "Star Streaming," *Report Brit. Assoc. for the Adv. of Sci., South Africa*, 1905, p. 257.

[2] Lewis Boss, "Convergent of a Moving Cluster in Taurus," *Astronomical Journal*, 604, September 1908.

begins. The gaseous ball cools down, particles are flung inwards by the contraction and flung outwards by the rate of revolution, and at various stages these two tendencies balance and equatorial rings are left self-sustaining in space. Finally the ball cools down to a liquid central sun and the rings break, their matter becomes aggregated into liquid spheres which continue to revolve in self-sustaining orbits and become the planets. There are many difficulties in the way of accepting this theory, the most urgent being the impossibility of an incandescent gas to remain in a sphere of such vast dimensions and revolve at such a great rate, owing to the lack of cohesion, for the molecules of a gas move at such a prodigious rate and are so small in bulk that gravitational force cannot control them.[1]

The question of kinetic energy comes into our theory also in connection with larger bodies. Many of the meteorites we see in the sky undoubtedly possess sufficient kinetic energy to overcome the attraction of the earth and pass therefore out of the range of the atmosphere and disappear into space. The great comets of 1843, 1880, and 1882 which followed each other round the same orbit like the two halves of Biela's comet, passed so near the sun that they almost grazed the surface, yet here again their kinetic energy was sufficient to carry them past the sun with its attracting mass 330,000 times that of the earth.

It is probable that, as a general rule, stellar bodies have kinetic energy far greater than their mutual attraction at even short distances apart, so that if they are not actually travelling in the same line towards each other, the rate of motion will be sufficient to carry them past each other in spite of the gravitational pull. There will be no collision, no vaporisation by the heat of contact, and the chances of close approach without collision are almost infinite as against direct impact.

[1] T. C. Chamberlin, "An attempt to test the Nebular Hypothesis by the Relation of Masses and Momenta," *Journal of Geology*, Chicago, vol. viii. 1900, p. 58; *ib. Science*, vol. xii. 1900; F. R. Moulton, "An attempt to test the Nebular Hypothesis by an Appeal to the Laws of Dynamics," *Astrophysical Journal*, vol. xi. 1900, p. 103.

What will happen may be judged from Sutton's Kimberley experiments. With the revolution of the sun a bulge of rock appears on the side of the earth facing the sun, and one on the opposite side, on the principle of the tides. Should now a body a thousand times the mass of the sun fly past the earth within the same distance, the gravitational pull will be a thousand times as great, and instead of a scarcely perceptible bulge, a great prominence of rock material would shoot out towards the body and an equal one on the opposite side of the earth. These prominences would follow the attracting body in its flight and would be drawn out spirally round the nucleus; when the earth was free once more of this disturbing influence, it would revolve with a spiral mass of rock coiled in space round it. The stars are conceived to be solid, having only an incandescent envelope on the outside, and the same thing would happen if two stars approached each other as we have just sketched out in regard to the earth with another and greater body flying past it. If we concede that the stars are perhaps liquid, their matter would be drawn out in a continuous stream, but in similar manner. It then becomes a question how would this matter contract; would it gradually gather into a sphere and go through the stages of evolution on the nebular hypothesis, or would the matter gather into knots and lumps of solid matter? In the latter case we should have the planetismal hypothesis to fall back on. We have not, however, to inquire what would happen to other stars under certain conditions; we merely want to know how the earth came to be joined up in the solar system, and a primary solid body will satisfy us. It will further be admissible to suppose, for the benefit of those who insist in cosmic evolution, that the primary sun out of which the solar system was developed was one which had gone through its life-history and had become a cold, inert body waiting for some event to start it afresh on its course.

To this cold, solid, primary sun approached a star of great magnitude, which, in passing, disrupted it, and drew out two spiral arms of solid meteoric matter. We are not concerned

with the sun and its heat, but it will not affect our theory if we suppose that it remained cold but its surface was vaporised by bombardment of meteorites and the heat of radio-active substances, or whether we suppose that in the disruption the central portion became vaporised, leaving the sun a liquid, incandescent ball. It will, however, help the understanding of the present theory if we accept the former alternative, because the earth at one time would have gone through a stage of incandescence such as the sun is in now from the same causes. We shall elaborate the subject of bombardment by meteorites later on, but it might be mentioned here that the failure to detect Becquerel's rays in the sun is no argument against assuming that part at least of the sun's heat is due to radium, because the distance of the earth from the sun is so great that no Becquerel radiation could ever be detected on the earth's surface.[1]

The meteoric matter in the spiral arms remained some time in scattered aggregates, but gradually the force of gravity began to draw it into clusters. The clusters grew into definite knots, and in time these became solid nuclei, on to which the meteoric matter fell. Thus were born the planets.

Our earth at this stage was a sphere perhaps one-hundredth of the mass of our present globe, and it has been growing ever since. It revolved with the central mass or sun, of which it indeed was part, till the outside force dragged it away and gave it a motion of its own. The attraction of the disturbing body supplied it with the kinetic energy sufficient to withstand the attraction of the sun, but not enough for it to pursue an independent course of its own; in other words, the two forces balanced. It is hard to conceive how, on the Laplacian theory, this matter could be whirled round while in a gaseous state at such a rate as to counterbalance gravitation.

In the early stages the meteoric matter pulled out of the sun pursued a general rotatory motion round the centre of the system; but the rates of motion of the individual members

[1] R. J. Strutt, "Radium and the Sun's Heat," *Nature*, 1903, p. 572.

and the eccentricities of their orbits varied according to mutual attractions and collisions with one another, and when the earth became sufficiently large to exercise predominant attraction among the swarm of smaller bodies, it gradually picked these up as it swept round in its orbit. Originally, therefore, the infall of meteorites was rapid and our conception of the rate of growth of the earth must not by any means be conditioned by the rate of infall of meteorites at the present time. In fact it is probable that what we do now receive are very largely the accidental windfalls received from other systems brought to us in comets. Of the primitive solar prominences there can be very scanty remnants left, the earth having had time to traverse every conceivable orbit that would have coincided at one spot in space with that of other independent smaller units. It is noticeable, however, that between Mars and Jupiter there is a belt of these smaller bodies which have persistently dodged the net of the larger planets, and have now settled into concentric orbits which practically put them out of reach. If a large comet were to come in and catch up the earth and supply it with sufficient kinetic energy to widen its orbit, then it might possibly happen that it would pass into the zone of the planetoids, and the process of growth would go on again as rapidly as it did in the commencement, until that region of the solar system was cleared.

In the early stages of the earth, when it was very much smaller than it is now and meteoric matter was falling freely upon it, the central nucleus was not under the pressure under which it is now, and it was probably comparatively loose in texture and varied in composition. The meteoric matter, both stony and iron, was aggregated in chaotic confusion, as the time had not elapsed, and the force had not been developed to separate them out. We must believe that even then there was an atmosphere but no water, for the meteorites we now find seldom show on analysis traces of water. Meteorites contain free and combined hydrogen in hydrocarbons and oxygen in the form of carbonic monoxide

and dioxide, so that the materials for forming water are there but the particular combination represented by water has not been usually detected, except in those which have lain some time in the open and have absorbed moisture from the atmosphere.

The loose material, what we might call a giant breccia, was continually being shifted by the impact of large meteorites and the alteration of the axis of revolution consequent in the disturbances in the position of the centre of gravity. This motion caused large segments to grind against one another, and the friction developed heat enough to melt the rocks along the line of movement where there were sufficiently fusible materials. If we take the moon as an example of the globe at this stage, we can see the outcome of these movements in the great craters on its surface. On the moon there is no water and consequently the volcanoes do not have an explosive stage, so that lava rises slowly and melts out great holes for itself. No lava, or very little, is extruded; this is due to the fact that there is no uplifting force which in terrestrial volcanoes is supplied by steam. When the motion ceases and all the rock is melted that can be, by the supply of heat available, the mass cools and contracts and the lava retires into the chimney that it has melted for itself. The features in the moon, the large craters, their diminution in size according to age consequent on decreasing movement in the body of the moon, their arrangement in short lines, and the presence of open fissures with one or two small craters on them, where the sides of the crack have not been sufficiently close to produce the friction and necessary heat for a great volcano, all these point to the probability of this being the explanation of the lunar volcanoes. G. K. Gilbert has already advanced the theory that the moon is the result of the assembling of meteoric matter, supposing this to have been collected round the earth in a system of rings as we now see in Saturn, but he imagined that all the volcanic phenomena on the moon were due to the impact of meteors.[1]

[1] G. K. Gilbert, "The Moon's Face," *Bull. Phil. Soc. Washington*, xii. 1893, p. 241.

On the earth at this stage the early volcanoes were probably of the same type as the lunar ones, for we have seen reason to believe that no water was then present on the surface. The brecciated structure of the whole earth, besides, would prevent the slow, continuous seepage of water, supposing it had been there, down into the depths where melting was in progress; while again the surface would not be cold enough to let it settle, so that looked at from many points of view the probabilities are that the early volcanoes of the earth were lunar in type.

The impact of large meteorites would form vast seas of lava on the surface, as already explained in the previous chapter, obliterating features already formed. The frequency of infall may or may not have been sufficient to cause permanent heating of the globe; we do not want internal heat in any stage of our history of the earth, and whether the interior of the earth is moderately warm or has the temperature of outer space does not affect our reasoning. The surface of the globe at this stage was, as we have said, probably too hot to allow water to rest upon it; we cannot in this matter of surface temperature take the moon as our example because the growth of the moon has stopped and cooled down, whereas when the earth was the size of the moon it was rapidly growing.

This process went on until the earth grew to within between $\frac{1}{30}$ or $\frac{1}{45}$ of its size at the present time, when the water began to combine and was condensed and collected in ocean basins. This is the epoch whence, on the present hypothesis, we should date geological time as Lord Kelvin dated his from the *consistentior status*, or overcrusting of his molten globe.[1] Before this was the astral period. From the time water collected the transport of weathered rock began. Disintegration can and does go on in a waterless, atmosphereless globe like the moon, by means of the alternate expansion and contraction due to the change

[1] *Trans. Roy. Soc. Edinburgh*, xxiii. 1862, p. 157; *Popular Lectures and Addresses*, 2nd Edit. 1891, p. 397.

of temperature from day to night, summer to winter; but the separation of the disintegrated rocks into soluble and insoluble portions, their transport to the oceans by rivers, and the consequent exposure of fresh surfaces to the attack of the agents of weathering—these can only take place when the water has settled down and the normal cycle of weathering has been established.

The earth's surface at this time consisted of basic rocks with iron in the metallic state. Similar rocks are still found at Ovifak and Niakornak in Greenland, in Brazil at São Francisco, in Russia at Nikolojenskaja Wosimskaja, and in Egypt. The effect of weathering on these was to carry a solution of iron and magnesium to the sea, and with it, in suspension, colloidal silica and mud. There were no sands in these primitive sediments, since, if we hold that meteoric matter was predominantly basic, there were no crystallised quartz crystals out of which to make sand grains. The salt of the sea was doubtless present in the rocks in the form of soda and chlorine, but the river waters did not contain anything like the amount they now carry in proportion to the other substances in solution. In the processes that went on subsequently the iron, magnesium and calcium became fixed, and the salt became by processes of concentration the principal substance left over.

In time the primitive sediments became thick and earth movements folded them into ridges; then for the first time a siliceous rock was exposed to denudation and grains of chert were carried with the muds to the sea. As time passed sedimentation went on continuously; earth movements successively upheaved, tilted, and folded the beds laid down till certain of the strata became crushed beneath piles of overlying beds, were caught in between contracting earth segments and became metamorphosed. Thus the first crystalline rock was formed which contained quartz, the crystalline variety of silica, as distinguished from the amorphous form of chert or chalcedony. Henceforward the resorting went on continuously. The quartz rocks were

upheaved, weathered, and the quartz grains transported to the sea as sand, which was then compacted into sandstone, and again upheaved, to be disintegrated and thus allow the sand once more to go on its journey to the sea; or the sandstone was buried under deep sediments and was metamorphosed and melted up with alumina and other bases, and returned by long processes of upheaval and denudation to the surface, once more to sustain the attack of weathering in the form of quartz grains in gneiss and granite. Thus, with quartz insoluble at the surface of the earth, the outer crust became gradually more and more siliceous, while the iron and magnesium seeped away in solution to the interior of the earth.

The following analysis of a meteorite that fell at Mount Dyrring in New South Wales, given by Mingaye, will show that we need not look elsewhere for the earth's materials than in the meteorites; it should be pointed out, however, that the nickel-iron according to Card is entirely oxidised, so that the water is probably all of terrestrial origin:—

ANALYSIS OF MOUNT DYRRING METEORITE

Water at 100° C.	.82	Manganese Oxide	Traces
Water on ignition	3.89	Potash	Traces
Silica	25.64	Cobalt Oxide	Traces
Alumina	1.32	Titanium Oxide	Traces
Iron Oxide, ferrous	29.90	Copper Oxide	Traces
Do., ferric	7.65	Gold	Traces
Lime	.01	Platinum	Traces
Magnesia	27.90	Iridium	Traces
Soda	.14	Paladium	Traces
Nickel Oxide	2.11	Tin	Absent
Chromic Oxide	.11	Vanadium	Absent
Sulphuric Anhydride	.15		
Carbonic Anhydride	.13		
Phosphorus pentoxide	.51		
Chlorine	.01		
	100.29[1]		

Of the twenty-one elements constituting more than one-hundredth per cent of the earth's crust given in Clarke's list,

[1] J. C. H. Mingaye, "Notes on and Analyses of the Mount Dyrring, Barraba and Cowra Meteorites," *Records Geol. Survey of N. S. Wales*, vol. vii. 1904, p. 4.

only four were definitely absent in this one meteorite. The following is the list referred to :—

ELEMENTS OF THE EARTH'S CRUST (CLARKE)[1]

Exceeding One-Hundredth per cent.

Oxygen	47.02	Phosphorus	.09
Silicon	28.06	Manganese	.07
Aluminium	8.16	Sulphur	.07
Iron	4.64	*Barium	.05
Calcium	3.50	*Strontium	.02
Magnesium	2.62	Chromium	.01
Sodium	2.63	Nickel	.01
Potassium	2.32	*Lithium	.01
Titanium	.41	Chlorine	.01
Hydrogen	.17	*Fluorine	.01
Carbon	.12		

* Absent in Mount Dyrring Meteorite.

Before we can, however, treat the earth's crust as a whole we must inquire into the quantity and action of the principal agent of metamorphision—water ; then we shall take the questions of heat, pressure, and movements in the rocks of the earth's surface, and so on, leading up to a full statement of the cycle of events just sketched out.

[1] F. W. Clarke, "Analyses of Rocks made in the Laboratory of the United States Geological Survey, 1880-1899," *Bull. U.S. Geol. Survey*, No. 168, 1900, p. 15.

CHAPTER IV

WATER

WATER exists on the globe in the great ocean basins. It is there exposed without shelter to the ever drifting currents of warm air, which suck up enormous quantities of water-vapour and carry this away to other parts. Should the warm air be cooled either by rising into higher regions of the atmosphere or by encountering colder currents, the air can no longer hold so much water-vapour in suspension, and there results a precipitation of rain. By far the greater portion of this is returned directly to the sea, only from 8 to 10 per cent finding its way over the land, and thus becoming available for fructifying the vegetation and feeding the springs and rivers.

On the land itself the same evaporation takes place, and quite 70 per cent of the rain which falls on the land comes originally from the exhalations of plants and to a smaller extent from the evaporation from lakes, rivers, soil, and so forth. That is to say, roughly, a third part of the rain that falls on the land is derived from the sea and two-thirds from the land. About a third part of the land rainfall is returned to the sea by means of rivers and underground channels, and on the actual proportion depends whether a land area is humid or arid. Should the amount of rainfall be such that a third part exceeds the amount discharged by rivers, then the sea is supplying more than it receives, and consequently the storage of underground reservoirs goes on till a time comes when these are charged to the brim and overflow, thus restoring the balance. Should

the discharge of the rivers be greater than the supply received from the oceanic evaporation, then the storage reservoirs become drained, springs dry up, and the land becomes arid. At the same time sufficient rain may fall to meet the needs of the inhabitants, and this is within their own control; man cannot tamper with the circulation of the air over the ocean, but he can, by conserving the water of rivers and by planting forests and by raising crops, increase the evaporation from the land surface, and consequently increase the rainfall. As a matter of fact, however, the amount of water discharged by rivers is only 22 per cent of the rainfall;[1] the residue is accounted for by the draining away of the water by subterranean channels discharging eventually into the sea, or supplying the deeper parts of the crust with water.

The following table is calculated from figures given by Risler; the amounts are kilogrammes of water per square metre used up in one month by the various plants mentioned; some of the water absorbed from the soil is used up in the plants themselves, but the greater portion is given off by transpiration.

AMOUNT OF WATER REQUIRED BY VARIOUS PLANTS (RISLER)[2]

Lucerne	102 to 203	kilogrammes	per square metre	per month
Meadow grass	93 to 218	,,	,,	,,
Oats	106 to 147	,,	,,	,,
Indian Corn	83 to 119	,,	,,	,,
Clover	106	,,	,,	,,
Wheat	80 to 83	,,	,,	,,
Rye	68	,,	,,	,,
Potatoes	28 to 41	,,	,,	,,
Vines	26 to 23	,,	,,	,,
Oak Trees	28 to 22	,,	,,	,,
Fir Trees	15 to 32	,,	,,	,,

Comparing these figures with those obtained from the estimates of evaporation from the surface of lakes as given by Hamberg for the lakes of Sweden, taking Dalboda as typical, we have:—

[1] Sir J. Murray, *Scottish Geogr. Mag.* vol. iii. 1887, p. 70.
[2] W. Schlich, *Manual of Forestry*, p. 44.

EVAPORATION FROM SURFACE OF LAKE DALBODA, SWEDEN [1]

	May.	June.	July.	Aug.	Sept.	
Evaporation in the open .	120.9	144.8	131.0	99.7	53.6	Kilogrammes per square metre.
Evaporation under trees .	34.1	46.4	41.8	28.1	23.1	

Taking the maxima, meadow grass will give off in the month 218 kilogrammes of water per square metre, whereas from the free surface of a lake in the hottest month 144.8 kilogrammes per square metre will be evaporated.

Von Honel takes 100 grammes of leaf substance dried, and calculates on this basis the amount of evaporation annually, in kilogrammes, for the various species of forest trees. It will, therefore, depend on the size of the tree as to how much water is actually given off from a given area of ground.

ANNUAL EVAPORATION FROM LEAF SURFACE REPRESENTED BY 100 GRAMS OF DRY LEAVES (V. HONEL) [2]

Aspen . .	95.970	kilogrammes	Oak . .	54.572	kilogrammes
Alder . .	93.300	,,	Maple . .	53.063	,,
Lime . .	88.340	,,	Larch . .	120.234	,,
Ash . .	85.615	,,	Spruce . .	13.501	,,
Birch . .	81.433	,,	Scots Pine .	9.426	,,
Beech . .	74.859	,,	Silver Fir .	7.179	,,
Hornbeam .	73.107	,,	Black Pine .	6.735	,,
Elm . .	66.170	,,	Mean . .	69.800	,,
Sycamore .	58.596	,,			

Besides ocean, rain, and river water, free underground water exists, and it is this that concerns us here more particularly. From the earliest times when geological questions began to be discussed, the question of underground water and especially its escape as springs, either cold or hot, and mineralised, has exercised the ingenuity of investigators, and recently the controversies over its origin have come very much to the fore. According to the Kant-Laplacian theory of the origin of the earth, all water now existing on the surface of the globe existed in the form of vapour in the atmosphere. The pressure of such water-vapour on the surface of the globe

[1] C. D. H. Braine, "The Influence of Forests on Natural Water Supply," *Report S. A. Assoc. for Advancement of Science*, Grahamstown Meeting, 1908, p. 117.
[2] C. D. H. Braine, *loc. cit.* p. 120.

is calculated by Fisher as 327 atmospheres,[1] and at a time when the earth was still molten, a certain amount of this water-vapour was forced into the liquid magma, just as carbonic acid gas may be forced into water under sufficient pressure. When now the crust began to solidify it walled up beneath it a zone of liquid magma charged with water-vapour, and every thickness added to the earth's crust by cooling has added to the envelope which kept in this water-vapour. When finally the surface of the earth became cool enough for the water vapour to condense and fill in the hollows of the crust, forming what we now know as oceans, the imprisoned water-vapour in the interior tended to ooze out in fissures and through pores in the rocks and to come to the surface as new formed water, or as Suess calls it, juvenile water [2]—the hypogene water of Posepny.

The difficulty in accepting this view, apart from the fact that we have seen reason to reject the Kant-Laplacian theory of the origin of the globe on which the idea of juvenile water rests, is that water-vapour, when held up in molten rock, is not retained mechanically but is occluded, that is to say, it is not free to escape at every small decrease in pressure, but remains entangled in the liquid until such time as the pressure is lowered to a certain point, when it all comes out at once with explosive violence. We see this very well in a volcanic eruption ; the lava rises in the chimney, and when the pressure reaches the critical point the water-vapour bursts out and blows off the head of the lava column, so that in the initial stage nothing but ash and pumice is ejected ; then, when the greater portion of the imprisoned gas has escaped, the lava rises and flows quietly over through a rift in the crater. The temperature at which extrusion of water-vapour occurs in flowing lava is a little above or a little below the solidification point of labrador felspar according to the pressure ;[3] this tempera-

[1] Rev. Osmond Fisher, *Physics of the Earth's Crust*, London, 1889, p. 149.

[2] E. Suess, *Prometheus*, vol. xiv. Nos. 690, 691, 692, Berlin, 1903; *Geographical Journal*, vol. xx. p. 517.

[3] E. H. L. Schwarz, "Petrographical Examination of the Volcanic Rocks of Matatiele, Griqualand, East," *Ann. Rept. Geol. Comm.* 1902, Cape Town, 1903, pp. 66-7.

ture is variously estimated at 1155-1180° C. (Doelter), 1230° C. (Joly), and 1463° C. (Day).[1] This extrusion of water-vapour is probably a second one, the first and more copious one occurring at a higher temperature within the vent. Volcanoes, therefore, would bring to the surface juvenile water, if the order of events had been as Fisher has described, but this water-vapour would not be able to escape in the hot springs and geysers which steadily flow year in year out for centuries, because the molten rock containing it, being at a higher temperature than the solidification point of labrador felspar, would retain it in occlusion.

Where the upholders of the theory of the surface origin for all deep-seated water in the earth's crust have laid themselves open to attack by the supporters of the opposite view, is in their assumption that the water descends through fissures and rifts in the earth's crust; where such orifices occur they form the channels by which gas, water, or liquid rock ascend, since in the interior of the earth such materials are under pressure, and the crack affords them relief. It is the capillary and the sub-capillary spaces which draw the water down to the depths of the earth's crust, as Daubrée showed experimentally, and we propose to examine into the nature of these channels and to show how the process is accomplished. We shall also advance evidence, later on, that these interspaces between the rock substances still persist down to the bottom of the 30 mile crust, and that therefore the rocks there are solid, and water exists there as water and not as vapour, as the acceptance of a molten globe would necessitate.

In tracing the origin of the water of the surface of the globe to its ultimate source we can only assume that it was brought in in the pore-spaces of the meteoric matter out of which we assume the earth was built, although it was not yet combined as water. The water of the oceans occupies the following spaces and has the following average depths:—

J. P. Iddings, *Igneous Rocks*, 1909, p. 84.

Ocean.	Area in square miles.	Average depth in fathoms.
Atlantic	34,300,000	2010
Pacific	67,700,000	2130
Indian	27,711,000	1830
Arctic.	5,700,000	850
Antarctic	5,600,000	1000
	141,000,000	2090

These are conservative estimates, and give a mean content of the ocean in round numbers of 300,000,000 cubic miles. R. S. Woodward gives 302,000,000 cubic miles; Dittmar 307,000,000 cubic miles;[1] Murray 323,722,150 cubic miles.[2] The largest estimate would not give more than 400,000,000 cubic miles. Now the volume of the globe as a whole is 260,000,000,000 cubic miles, so that the ocean volume represents .11 per cent or at most .15 per cent of the whole globe or from .02 per cent to .03 per cent by weight. This is an amount that, represented by uncombined hydrogen and carbon dioxide, could very well have been carried by meteorites even after a prolonged sojourn in the vacuum of space, and presents no difficulty in deriving the water of the globe from assembling meteorites.

This water lies on a floor of mud, sand, or rock, none of which are so compact that they cannot contain water in the interspaces between the grains. The following estimate of pore-space in the various materials which compose the floor of the ocean will illustrate this point:—

		Pore space, by volume (Buckley).[3]
Sand, spherical grains all equal sizes	maximum	47.64 per cent
	minimum	25.95 ,,
Clay allowed to settle in water	maximum	79 ,,
	minimum	50 ,,
Sandstone	maximum	28 ,,
	minimum	5 ,,
Limestone	maximum	13 ,,
	minimum	.5 ,,
Granite	maximum	.6 ,,
	minimum	.19 ,,
Rhyolite		.019 ,,

[1] William Dittmar, "The Composition of Ocean-Water Salts," *Narrative of the Cruise of H.M.S. Challenger*, vol. i. pt. 2, 1885, pp. 951 and 980.

[2] Sir J. Murray, *Scottish Geogr. Mag.* vol. iv. 1888, p. 59.

[3] E. R. Buckley, "On the Building and Ornamental Stones of Wisconsin," *Bull. Wisconsin Geol. and Nat. Hist. Survey*, No. 4, 1898, Madison, Table v. p. 400.

The last on the list is a glassy rock, and the pore-space in it is naturally exceedingly small, but still appreciable; in rocks of crystalline structure the pore-space never goes below .1 per cent. In clay the explanation of the large pore-space is the mutual attraction of the small particles, so that these tend to join end to end and to form an openwork arrangement which cannot be destroyed by ordinary pressure; in artificial puddling or in the rolling action which takes place when clays are squeezed in earth movements, the particles gradually assume parallel positions, and the pore-spaces are reduced to the proportions existing in sandstones. With arenaceous deposits the grains are as a rule too large to form this open-work spacing; on the contrary the smaller grains pack in between the larger ones and reduce the pore-space very considerably; in the minimum given in the list the rock is exceptionally compact, and microscopical examination showed that the grains had been enlarged by secondary growths and cemented by silica. In limestone secondary enlargement of the grains has usually taken place, thus accounting for the small pore-space, while in igneous rocks the grains have grown up in the liquid magma and mutually interlock.

The application of these facts in determining the holding capacity of the floors of reservoirs is well-known. A clay bottom is as porous as a sieve unless the material is specially worked up and puddled; in South Africa it is the custom in such cases to drive a flock of sheep over the mud floor after the first water has sunk away, and thus the kernel or crumb structure of the clay is broken down. With a sandy floor these troubles are not encountered, since in nature the grains are seldom so evenly matched in size as to form a sieve; in most cases the grains are of all sizes, and some clay exists as well. The larger grains thus lie as it were in a matrix of smaller grains and these in a matrix of clay, so that nearly all the pore-space is filled in.

As regards the ocean floor, the amount of sandy material lying spread over it is small and confined to coast margins, whereas in the great expanse of the open ocean the bottom is

covered with fine materials, red mud, shells of foraminifera, radiolaria, diatoms, and coccoliths, cosmic and volcanic dust and so forth. Under the immense pressure of water which exists in the deeper portions of the ocean, the siliceous and calcareous matter becomes dissolved, leaving a flocculent precipitate behind, which may partially or wholly replace the original shells as they fell from the surface. The process reduces the size of the particles lying on the floor and adds to the porosity; in no case has it been recorded that secondary

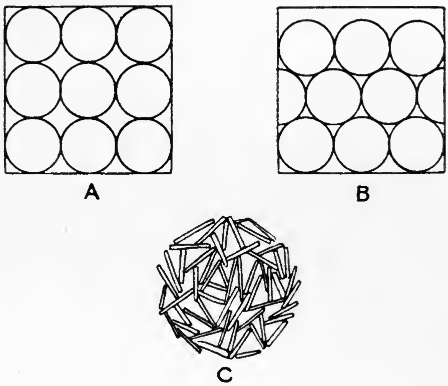

FIG. 3.

A and *B*.—The packing of equal sand-grains in the loosest and most compact manner. If the grains are irregular, then the smaller ones fit in between the larger, and considerably decrease the pore-space. *C*, a "crumb," formed of kaolin scales held together by the surface tension of the film of water with which they are covered. Soil crumbs have, in addition to the kaolin scales, minute grains of sand.

infiltration of cementing material has taken place, reducing the pore-space, at least while the sediments lie undisturbed on the sea floor. In calcareous sands along the coast in warm regions a certain amount of solution and redeposition goes on beneath the sea; for instance in South Africa in the Mossel Bay harbour works the bore cores pierced 8 or 10 feet of loose sand, then a layer an inch to two inches thick of very hard, compact, cemented sand, then below, loose sand for 20 feet or more down to solid rock; but such hardening can only take place near the land, where alternating conditions of temperature and composition of the water and varying

circulation are in progress. As a general rule we can assume that the floor of the ocean is covered with a loose, porous deposit which allows the free percolation of water ; we cannot say that it lies in a water-tight reservoir.

Beneath the deep-sea sediments lie the ordinary rocks of the earth's crust. We have seen reason to believe that a large portion of the ocean floor is covered with ordinary sediments, the relics of foundered continents ; all these have a high percentage of pore-space, but under these again would always come the crystalline rocks whose pore-space can be safely taken as constituting a minimum of .1 per cent of the volume. Let us inquire what these pore-spaces are, and how they act in regard to the water lying above them.

Van Hise divides these into three groups :[1]—

	Circular openings.	Sheet openings.
Super-capillary, with a diameter exceeding .	.508 mm.	.254 mm.
Capillary, with diameters between . . .	.508 mm. and .0002 mm.	.254 mm. and .0001 mm.
Sub - capillary, with diameters below .	.0002 mm.	.0001 mm.

By circular openings are meant those which, strictly speaking, have a perfectly circular section, and the above figures are calculated on this basis ; in nature, however, this type of opening is such as exists between grains of sand, quite irregular in outline but having fairly continuous walls along their courses ; the effective size of the openings as regards capillary attraction, therefore, will vary from the calculated ones according as they depart from the circular and approach the shape of the sheet openings. Sheet openings are such as occur between the laminæ of a shale or between the bedding planes of rocks ; as will be noticed the limit for these is half that of the circular openings. Circular openings, in a sandstone for instance, widen and narrow according to the distribution of the grains, but they are practically continuous throughout the length of any one stratum ; in super-capillary openings, which allow

[1] C. R. van Hise, "A Treatise on Metamorphism," *Monographs of the U.S. Geol. Survey*, vol. xlvii., Washington, 1904, p. 134.

the free passage of water, they conduct the water more or less as if it were led in an artificial pipe. In the artesian water drawn from a sandstone beneath Chicago the loss of head from the point at which it is absorbed, from the surface 200 kilometres distant, to the city, is 50 metres, that is to say the water spouts up 30 metres from the bore-holes, while the point of entry is 80 metres above Chicago.[1] While these channels are co-terminous with the extent of the particular bed, they are bounded above and below by the planes of bedding. It is less easy to establish the continuity of the capillary and sub-capillary openings, especially in crystalline rocks, where they are too small to be noticed even with high powers of the microscope; but the fact that samples taken from a given area of granite show on analysis a fairly uniform amount of moisture, the Bergfeuchtigkeit of the Germans, indicates that there is a freedom for the passage of moisture throughout the mass.

Super-capillary openings are those which allow the free passage of water, and the movement of water through them follows the ordinary laws of hydrostatics. They exist in ordinary sands and gravels where the grains are fairly uniform, and the smallest do not average less than 3 mm. diameter. Slichter arrived at this figure by first arranging three spheres of 3 mm. diameter in a triangle; the intervening space then measures from the point to the base about .508 mm., that is to say the opening would just be capillary. If now we calculate the total pore-space in a sand with equal grains packed in this manner, we shall find that it is 43 per cent greater than if we were to make all the intervening spaces between the grains tubes of .508 mm. diameter. Hence there must be channels greater than .508 mm. diameter, that is to say, there must be super-capillary openings in the mass.[2]

The rate of flow in a super-capillary opening is repre-

[1] Frank Leverett, "The Water Resources of Illinois," *Seventeenth Ann. Rept. U.S. Geol. Survey*, pt. 2, 1896, p. 805.

[2] C. S. Slichter, "Theoretical Investigation of the Motion of Underground Water," *Nineteenth Ann. Rept. U.S. Geol. Survey*, pt. 2, 1899, p. 305.

sented by the formula $V = \sqrt{2gH}$, where V is the velocity in centimetres, g the force of gravity, and H the height in centimetres between intake and outlet. Thus if H is one atmosphere or a pressure of 10.33 metres of water, the velocity would be $\sqrt{2 \times 981 \times 1033}$ or 14.24 metres per second. Even in artificial tubes this rate is never attained as the friction of the walls exercises a restraining influence, and in natural openings the formula is quite inapplicable owing to the tortuous course of the underground passages and the fact that they continually form syphons which act as pressure traps.

As a rule, however, the grains of sandstones average far less than 3 mm. in diameter and there are, therefore, no super-capillary openings; in fine grained sandstones, shales, and in crystalline rocks, the openings are always capillary or sub-capillary. On the surface of the ground sheet openings of super-capillary size exist in joints and bedding planes, fault openings and such like; in the deeper portions of the earth's crust, in the fissures produced temporarily by folding and faulting. On the surface they allow the free percolation of water and are the sources of the greater number of springs; in the depth of the earth's crust they form channels by which water ascends as it is squeezed out of the capillary and sub-capillary pore-spaces in the rocks by the great pressure. The deep-seated super-capillary openings will be dealt with in the chapter on the work of underground water.

Capillary openings are those which are small enough to be able to draw up water and sustain it at a height above the gravity level. Capillary attraction depends on the tendency of molecules of water to attract each other. When the molecule of a liquid is surrounded on all sides by other molecules, the attractions in the various directions neutralize each other so that the particles do not have their motions affected by this force; at the surface, however, there is nothing to counterbalance the pull in the downward direction, so that there is an excess of force tending to cause a motion

of the particles away from the surface. If now there is brought into the liquid a foreign body, which is wetted and thus capable of exerting attraction, the liquid creeps up the sides as far as the pressure of the neighbouring surface will allow. If the surface of the body is not wetted, that is, exerts a repulsion on the liquid, then to the downward attraction of the liquid particles there is added this further repulsion, and the surface of the liquid will be curved downwards. In Nature we know of no cases where the surfaces of the cracks are not wetted. If two vertical surfaces dipping into the water are brought close together, a sheet of water is drawn up to a height dependent on the distance between them; if they are 1 mm. apart the water will rise 1.66 cm., or if a tube is used, one with a diameter of 1 mm. will draw the water up to double this height, that is 3.32 cm. For other distances apart and other diameters, the height to which the liquid is drawn is inversely as the diameters of the openings. Thus in spaces which we take to be capillary, that is, .5 mm. for circular and .25 mm. for sheet openings the height will be 6.64 cm.; for the limiting diameters of capillary openings, .0002 mm. for circular and .0001 mm. for sheet openings, the height will be 166 metres.

The above values are calculated for temperatures of 20° C. and decrease with the rise of temperature, and are not applicable at all to water gas. However, we see that if water lies on a stratum of rock with capillary openings it will be drawn in to a considerable distance by the action of molecular attraction; add to this the pressure which exists at the bottom of the sea, gravity and the constant tremblings of the earth which by alternate pressure and release of pressure act as a pumping force, we see that water must be drawn far down into the superficial covering of the earth's crust.

Capillary openings exist in sands and muds whose grains range below 3 mm. and above .0012 mm. in diameter, and to a large extent in the bedding planes and laminæ of rocks near the surface. Water circulates freely through capillary openings, and will drain out into wells and bore-holes on to

which they open. The production of dendrites from the deposit of manganese oxide from solution well illustrates the nature of these openings; the space has been sufficiently narrow to allow the deposit of a film of ore when the water of saturation evaporated.

Glass attracts water; Quincke found that with a film of silver on glass reduced to .00005 mm. thick, the attraction of the glass could still be exerted through it.[1] A glass surface, then, in continuity with water will gradually cover itself with a film of water .00005 mm. thick, which will adhere so that no mechanical force will remove it. All rock minerals known exert the same attraction for water. In channels of capillary and super-capillary size the walls will be covered with this adherent film, which will not move with the flow of the water but will form a surface over which the main body flows. If, then, two such glass surfaces are brought within .0001 mm. of each other, each will have an adherent stationary film of water, and no other water can gain admittance. For circular openings the diameter will be double, namely, .0002 mm. These are the sub-capillary openings.

If we take the average pore-space of crystalline rocks as .1 per cent, 1 cubic centimetre will have .001 cubic centimetres of its spaces empty; it will therefore require 100 sub-capillary cracks of the dimensions .00001 cm. wide, 1 cm. deep, and 1 cm. in length, to account for this pore-space, in other words, every cubic centimetre of rock will be traversed from side to side by 100 sub-capillary sheet openings. These will always be filled with water while the rock is in the earth's crust, and the amount is for a ton of granite roughly 1 lb. of water for every .1 per cent of pore-space. This is the Bergfeuchtigkeit of the Germans, translated by water of imbibition, as distinct from water of saturation, which drains away when the surrounding water is removed. The following figures are given by Buckley for Wisconsin granites:—

[1] M. Quincke, "Über die Entfernung, in welcher die Molekularkräfte der Capillarität noch wirksam sind," *Poggendorff's Annalen*, vol. cxxxviii. p. 402.

TABLE OF ABSORPTION OF WATER IN WISCONSIN GRANITES (BUCKLEY)[1]

Pore-space.	Dry weight of sample.	Specific gravity.	Weight of water absorbed after soaking 72 hours.	Percentage weight of water.
.1	355.69 grammes	2.713	.143	.040
.2	372.91 ,,	2.639	.295	.079
.33	367.45 ,,	2.659	.415	.113
.39	338.82 ,,	2.642	.505	.149
.52	373.65 ,,	2.639	.74	.200
.62	370.51 ,,	2.646	.88	.230

If we take the outer crust to be $\frac{1}{30}$ by volume or $\frac{1}{65}$ by weight of the whole earth, then, assuming that the pore-space is only .1 per cent the volume of this underground ocean can be estimated to be 866,666 cubic miles. It may be added that van Hise estimates the average of the pore-space of the rocks comprising the earth's crust to be from .52 to 1.12 per cent, but in dealing with the earth's crust down to the bottom, it is safer to consider it to consist of the most compact crystalline rock known, therefore .1 per cent will be more nearly right for the general average.

Wherever, then, there is rock, sub-capillary spaces if not larger ones abound, and along the walls of these water creeps. We cannot conceive what the order of events is when this water reaches the zone where temperatures are above the vaporisation point of water. We shall later see reason to doubt whether these high temperatures do exist in the interior of the globe, but we can assume the popular conception to be the correct one for the sake of argument. We know that the water cannot be forced back along the pore-spaces and the net result can be gauged by the often quoted experiment of Daubrée.[2]

The experiment was conducted with a disc of compact sandstone, two centimetres in thickness and sixteen centi-

[1] E. R. Buckley, "On the Building and Ornamental Stones of Wisconsin," *Bull. Wisconsin Geol. and Nat. Hist. Survey*, No. iv. Madison, 1898, Table v. p. 400.

[2] A. Daubrée, "Rapport sur les progrès de la Géologie expérimentale, 1867"; *Études synthétiques de géologie expérimentale*, Paris, 1879, p. 236.

metres in diameter; this was clamped between the two halves of a copper vessel, the upper half open to the air and the lower one connected by three ways cock either with the air or with a pressure gauge. Water was poured on the surface of the sandstone and the whole apparatus was raised to a steady temperature of 160° C.; an hour and a half was allowed for everything to adapt itself to this temperature. The lower reservoir during this time was in connection with the air. On shutting off the communication of the lower reservoir with the air and connecting it with the pressure gauge, the latter gradually rose to 1.9 atmospheres. On releasing the pressure and reconnecting with the gauge the same effect was produced time after time. The experiment shows that the water had traversed the sandstone through the pores against pressure, and that, at a temperature above the vaporisation point of water, the action not only takes place but is accelerated, transcending all rates of imbibition and transudation at ordinary temperatures; but the most important point is that the lower surface, continually dried by the heat of the apparatus, restores the equilibrium of moisture in the rock by the attraction of molecules of water which saturate the neighbouring portions on the upper surface.

We have every reason to assume, therefore, that there is a continual suction of water from the floor of the ocean down through capillary and sub-capillary pores in the rock, whether the bottom of the crust be immensely hot so that the water there is vaporised, or whether it be cold as we shall see reason to believe it to be. The rate of flow we do not know, but with practically unlimited time and the enormous surface of the ocean, which occupies nearly three times the surface of the globe that land does, we have a sufficient source for all subterranean water without drawing on an imaginary saturated primitive magma.

The water sucked into the crevices of rock will be sea-water with all the various ingredients inherent in it, varying according to Dittmar from 3.301 per cent in the southern portion of the Indian Ocean to 3.737 per cent in the middle

of the Atlantic. The various compounds do not concern us here, as in the selective absorption of rocks, it is possible to obtain concentrations of one or other of the ingredients; suffice it to state that the following elements have been detected by Forschhammer:—*oxygen, *hydrogen, *chlorine, *nitrogen, bromine, iodine, fluorine, *sulphur, *phosphorus, *carbon, *silicon, boron, silver, *copper, lead, zinc, *cobalt, *nickel, *iron, *manganese, *aluminium, *magnesium, *calcium, strontium, barium, *sodium, and *potassium.[1] To this list must be added elements detected by other observers: Arsenic, lithium, cæsium, rubidium, and *gold. Those marked with an asterisk are the elements commonly met with in meteorites.

As regards the sodium chloride one can actually see with high powers of the microscope the small cubes of salt in the liquid filling the bubbles in granitic quartz. Sandberger found 2 per cent of salt in the quartz in the granite of the Friesenberge in Baden Baden. Schweiger found .1 per cent in porphyry from Kreuznach, of which .06 was made up of chlorides of soda and potash, .02 of calcium chloride, and .012 of magnesium chloride. Gautier found in pulverised granite the following substances:—

Sodium sulphide	.108 gramme
Potassium sulphide	Trace
Alkaline chlorides and sulphates / Salts of iron, magnesium, and calcium	Faint trace
Sulphuretted hydrogen	4.3 cc.
Carbonic acid	6.8 cc.
Nitrogen	2.3 cc.
Ammonia (organic matter)	Trace *

* R. Delkeskamp, "Fortschritte auf dem Gebiete der Erforschung der Mineralquellen," *Zeitschr. d. prak. Geol.* vol. xvi. 1908, p. 413.

Such substances we may assume exist in the water held up in the pore-spaces, but far more convincing are the exhalations from volcanoes and solfataras, in which, besides water, there have been observed — ammonium chloride, hydrochloric acid, boric acid, sulphuric acid, sulphuretted hydrogen, hydrofluoric, hydrobromic, hydriotic acids, carbonic

[1] G. Forchhammer, *Phil. Trans. Roy. Soc.* clv. p. 295.

acid, vapours of sulphur, selenium, iodine, as well as traces of hydrogen, sulphates and chlorides of lime, soda, magnesium iron, and copper. All these substances are not necessarily the actual salts carried down from the bottom of the sea and thus returned to the surface. In its passage through the rock-pores water dissolves large quantities of substances and redeposits those which it already possesses, so that when it comes again to the surface quite a new category of dissolved salts may exist in solution.

In ordinary well-watered countries the fresh water from the land percolates through subterranean cracks and may be struck in bore-holes in islands lying off the coast, but where the supply of fresh water is insufficient, sea water may be drawn in through the capillary crevices and can be traced far inland, as in Egypt.[1] Bore-holes along the South Coast of England from which water is pumped yield salt water if the water is drawn from them faster than the underground springs can supply fresh water.

Finally water may be permanently absorbed by the rock substance in the form of hydrated compounds. These are extremely common in metamorphic rocks and the subject will be more fully treated in dealing with these; in this connection it will be sufficient to note that in rocks of this type, water of combination rises to as much as 4.42 per cent, and Clarke estimates the average in all rocks, shales, sandstones, limestones, volcanic, and crystalline rocks at 1.64 per cent. The imprisoned water is practically lost to circulation, although in the long run it is returned to the surface on exposure of the rocks containing the hydrated compounds and their subsequent denudation.

[1] C. Natterer, *Denkschriften d. math.-naturw. Cl. d. k. Akad. d. Wiss. Vienna*, 1898.

CHAPTER V

THE WORK OF SURFACE WATER

WATER acts as a solvent and as a vehicle for transport of material. Its power of dissolving substances such as common salt is known to every one, but that it is capable, given time, to dissolve the most refractory substances, such as quartz and gold, is not generally recognised. Water which has dissolved such substances will naturally carry them away with it when it flows down to a lower level, but besides transporting substances in solution it carries matter such as sand and mud in suspension.

If we take a rock from the surface of the earth where it has been exposed to the percolation of water, and then take a portion some depth down where it is quite fresh and unaltered, we shall find on analysis that certain of the substances have been leached out by the water and have been carried away. The following example is given by Irving and Van Hise of diabase from Michigan :—

ANALYSIS OF FRESH AND ALTERED DIABASE

	Fresh.	Altered.
Water at 100° C.	.15	.29
Water at red heat	2.34	13.54
Carbonic oxide	.38	.38
Sulphuric oxide	.03	...
Phosphoric oxide	.13	.14
Silica	47.9	41.6
Titanium oxide	.82	3.79
Aluminium oxide	15.60	37.20
Ferric oxide	3.69	3.21
Ferrous oxide	8.41	.30
Chromic oxide	Trace	...
Nickel and Cobalt oxide	.10	...
Manganese oxide	.17	.08
Barium oxide	.05	Trace
Lime	9.99	.23

	Fresh	Altered.
Magnesia	8.11	.02
Potash	.23	...
Soda	2.05	.07[1]

The greater portion of these constituents are in the fresh rock locked up in certain definite combinations, thus the barium oxide, lime, potash, and soda are combined with alumina and silica to form felspars, while the iron and magnesium, and some of the alumina are combined with silica to form augite. The first point to notice in the table is the percentage increase in the alumina in the altered rock; the other constituents have diminished in amount, but this one is left behind, therefore water has the power of decomposing a chemical compound, and is able to select certain of the component substances for solution and leave the residue behind. The second point is that the silica has at the ordinary temperature of the atmosphere gone into solution. The large amount of magnesia and ferrous iron which has disappeared is also noteworthy in view of the absence of these in sea-water; with this point, however, we shall deal later.

Let us suppose that all the alumina has been left behind, which is not strictly correct, for a small amount does go into solution but we can neglect this for the moment, then we can calculate how much of each of the other minerals has been dissolved; all the potash has disappeared, therefore we put it 100 per cent and so on with the others.

Percentage Loss of Substances in Diabase when Weathered

Potash.	Soda.	Lime.	Magnesia.	Iron oxide.	Silica.	Alumina.
100	98.57	99.04	99.90	87.81	63.57	0

This table requires further explanation in that the iron and magnesia have been leached out of combination with silica, in the augites, and all the silica that has disappeared has come from this combination. The remaining silica is locked up with the alumina, which, with the addition of the water, has formed hydrous aluminium silicate, or kaolin or clay; this is an extremely insoluble substance though it

[1] R. D. Irving and C. R. van Hise, "The Penokee Iron-bearing Series of Michigan and Wisconsin," *Mon. U.S. Geol. Survey*, vol. xix. 1892, p. 357.

readily forms compounds with soda and lime to form felspar. The ultimate result of the weathering will be to leave the kaolin behind as the sole compound that has resisted solution. In an acid rock like granite or gneiss containing free silica in the form of quartz, the amount of silica dissolved would be proportionally less.

PERCENTAGE LOSS OF SUBSTANCES IN GNEISS WHEN WEATHERED

Potash.	Soda.	Lime.	Magnesia.	Iron oxide.	Silica.	Alumina.
83.52	95.03	100.00	74.70	14.35	52.45	0

Even such a very refractory substance as gold will dissolve in water in nature, and either the water will carry it away into the sea where it remains in solution in quantities which are exceedingly small, but, were they recovered, would, according to Liversidge, yield 75,000 million tons of gold;[1] or it may be precipitated by organic matter and certain inorganic substances and form nuggets in the gravel at the bottom of the river. There can be little doubt now that gold dust and nuggets in alluvial deposits are carried in this way and not in suspension, as creeks have been watched which yield fair-sized nuggets every few years after the gravel has previously been worked out, yet the sides of the gullies, the disintegration of which has supplied the gold, contain rocks where the metal is so finely distributed as not to be visible with the naked eye.[2] (See Frontispiece.) The discovery of nuggets in New Guinea by Liversidge with concentric structure, like the little lime carbonate nodules that form in calcareous springs, is conclusive proof that in their case, at any rate, the gold has been deposited from solution.[3]

The solvent action of water is aided by certain substances of which the carbonic acid, washed out of the atmosphere by rain, is the most commonly noted and the one whose action is the simplest.

[1] A. Liversidge, *Proc. Roy. Soc. N.S. Wales*, 1895, p. 195.

[2] E. H. L. Schwarz, "Gold at Knysna and Prince Albert," *Geol. Mag.* Dec. 5, vol. ii. 1905, p. 369.

[3] A. Liversidge, "Gold Nuggets from New Guinea Showing a Concentric Structure," *Journ. Roy. Soc. N.S. Wales*, vol. xl. 1907, p. 161.

The amount of carbonic acid gas available is exceedingly small, as it exists in the atmosphere in such minute quantities, 2.76 to 3 cubic centimetres in 10,000, but then it is in constant currency. Animals, living and decomposing, artificial fires and exhalations from volcanoes are continually pouring forth immense quantities into the air, while on the other hand plants are busily abstracting it for the constructing of their cellulose, and animals are fixing it for their bones, carapaces, and shells. Rain water contains on an average .00065 grammes of carbonic acid for every 10,000 cubic centimetres or grammes of water; this minute amount never appreciably diminishes however much the demands of the various activities of nature are upon it. Water containing weak carbonic acid solution readily dissolves limestone. The ability to hold lime carbonate in solution is dependent on the acid gas remaining dissolved in the water, and if by any means, such as high temperature without pressure, the gas is expelled, the carbonate of lime is thrown down. This point is well illustrated in the calcareous sands which occur along the coasts of warm climates. The shells of the prolific shore mollusca are washed up in enormous quantities, dragged to and fro by the breakers till they are reduced to grains small enough to be caught by the wind when the ebbing tide leaves them exposed. Thus great dunes of sand comprised of comminuted sea shells are built up along the shore. Rain falls on these; water lies in the interstices between the grains and dissolves a certain amount of lime; when the water evaporates under the heat of the sun the lime is thrown down and cements the grain. If now by earth movement, this hardened sand is carried below sea-level one would expect that the sea-water would dissolve the cement and set free the grains. The opposite happens. There is certainly some lime dissolved, but at ebb tide the rocks are left with a shallow layer of sea-water above them which becomes warmed by the sun, the carbonic acid gas is driven off and the dissolved lime is thrown down; the consequence is that the rocks become much more hardened than

Fig. 4. Gericke Point, George

A stone reef formed of wind-blown sand, hardened originally by percolation of rain-water, and then again hardened by sea-water. Where the waves are breaking, the rock is similar to that in the foreground.

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before and the jagged ledges are formed which Branner has named stone-reefs.[1]

Whether the carbonic acid has any marked action on silicates in nature is doubtful, and the solution of the lime and soda in combination with aluminium silicate in felspars is probably due to the action of water alone. Silica is a much more powerful acid than carbonic acid, having a heat of neutralisation equal to nitric and hydrochloric acids, although we can only notice this when pressure renders the molecules of the silica mobile enough to compete with carbonic acid molecules; but the fact remains that under suitable conditions silicic acid decomposes carbonate of lime, produces lime silicate, and sets free carbonic acid. Water again, which at ordinary temperatures is barely acidic, at 300° C. becomes as strong an acid as silica, and at 1000° C. it is 80 times, and at 2000° C. 300 times as strong as silica; these results, however, have been obtained by Thomsen by extrapolation.[2]

The organic acids produced by the plant roots are powerful disintegrators when sufficient time is allowed for them to act. The familiar illustration of this is the experiment of germinating a pea on a polished slab of marble; the root creeps over the surface and when, after a week or so, the young pea-plant is taken away, there will be noticed a groove corresponding to the shape of the root, where the acid secreted by the root tip has corroded the marble. The acids elaborated by growing vegetation are carbonic, formic, hydrochloric, oxalic, and citric acids. Czapek doubts whether any but the first two are formed by the roots themselves; the others which are found in the soil are elaborated or set free by micro-organisms.[3] The

[1] J. C. Branner, "Stone Reefs on the north-east coast of Brazil," *Bull. Geol. Soc. America*, vol. xvi. p. 1, 1905.

[2] Svante Arrhenius, "Zur Physik des Vulcanismus," *Geologiska Foreningens i Stockholm Forhandlingar*, vol. xxii. 1900, p. 395; *Geol. Mag.* 1907, p. 174.

[3] F. Czapek, *Progressus rei botanicae*, 1907. According to later researches, however, it appears that roots under certain conditions do by themselves elaborate organic acids; thus, with a limited oxygen supply, buckwheat and barley form acetic acid, oats and maize formic acid, and beet-root oxalic acid. J. Stoklasa and A. Ernst, *Jahrb. wiss. Bot.* (*Pringsheim*), vol. xlvi. 1908, No. 1, p. 55.

acids formed from the decomposition of plant substance are humic, ulmic, crenic, and apocrenic acids.

The main work of organic acids in soil is to dissolve iron salts. They are particularly abundant in regions where carbonates such as limestone are absent, for such weak compounds readily combine with the organic acids and neutralise them, giving off carbon dioxide. They are also abundant in regions of heavy precipitation where the soil becomes water-logged, or where the drainage of the soil is unable to carry away the contained acids as they are formed. Such regions are characterized by sour soil, which will show an acid reaction when tested with litmus. In such regions the waters that run from off them are heavily charged with iron in solution, and at the bottom of lakes receiving the water, or under the soil where the water stagnates, large deposits of hydrated iron-oxide accumulate.

One is led to infer from this that in the early stages of the earth's geological history, when highly ferruginous rocks were exposed on the surface, that plant life may have played an important rôle in removing the iron. It is certain that the first organic beings were plants, and it is equally true that the first land organisms were plants. I am not referring here to the micro-organisms with which I shall deal later, but the higher plants; mosses and fresh water algæ especially probably extended over the land as peat bogs do now, and from the drainage under them issued continuous streams of water heavily charged with iron with which the first ocean was liberally fed.

Sulphides and sulphates are present in most of the basic rocks, and are readily absorbed by water. One of the commonest accessory minerals is iron pyrites, and this when not fully oxidised produces the easily soluble ferric sulphate. Doelter found that pyrites, galena, stibnite, mispickel, chalcopyrite and bournonite were to a certain extent soluble in pure water; he had, however, to keep them at a temperature of 80° C. for four weeks, but Nature would be able to accom-

plish the same at ordinary temperatures, given longer time.[1] Once one compound becomes dissolved, it reacts on others and more substances can be taken up. Thus in the case of zincblende, Doelter found that it was necessary to add sodium sulphide to the solution before any appreciable effect could be noticed. Other natural aids to solution mentioned by Becker are sodium and potassium chloride, sodium silicate, sodium sulphydrate, and sodium carbonate.

The rate of solution of substances at the surface of the earth, if we rely on pure water alone, is slow; but with the help of micro-organisms it is appreciable. The best example of this is given by Treub who visited Krakatoa two years after the great eruption of 1883; the island lies in the Straits of Sunda, and at the time of the eruption was converted wholly into a mass of glowing cinders, so that every vestige of organic life was effectually exterminated. Yet when Treub visited it the surface was slimy with microscopic plant-life busily breaking down the silicates into clay, elaborating food for the higher plants out of the combined potash, phosphorus, and so on, and yielding albuminoid substances to constitute the perfect soil.[2] Such is the picture that we can imagine for the early stages of the geological history of the earth; but whereas in Krakatoa the seeds of the higher plants were being wafted by the air and thrown up by ocean currents on the shore, and were already beginning to grow and propagate two years after the catastrophe, in the case of the earth in the early stages the soil had to wait for æons of time before these more elaborately organised plants could take advantage of it.

Turning now to the opposite side of the action of water on the surface of the earth, namely, the transport of material, both dissolved and the residue left after solution; we shall have to discuss these questions very briefly as they are fully treated in the general text-books.

[1] C. Doelter, *Tschermak's Mitteilungen*, vol. xi. 1889, p. 319.
[2] M. Treub, "Notice sur la nouvelle Flore de Krakatoa," *Ann. Jard. bot. Buitenzorg*, vol. vii. 1888, p. 213.

The ideal rock type to which the primitive earth nucleus belonged was an ultra-basic rock consisting of :—

Nickeliferous iron: nickel, 6 – 20 per cent; cobalt, .5 – 2 per cent; copper, .006 – .02 per cent.

Bronzite	composed of	magnesia and silica.
Olivine	,,	iron, magnesia, and silica.
Hortonolite	,,	iron, magnesia, manganese, and silica.
Monticellite	,,	lime, magnesia, silica.
Anorthite	,,	lime, alumina, and silica with traces of potash and soda.
Apatite	,,	calcium phosphate.
Chromite	,,	iron, chromium, oxygen.[1]

The rock type to which the rocks now on the surface of the earth approach, taken as a whole, is granite, an acid rock consisting of :—

Silicic acid or silica.

Hornblende Black mica and augite		Composed of iron, magnesia, and silica with lime, alumina, soda, manganese, titanium, lithium, zirconium, niobium, cerium, and fluorine.
White mica	composed of	water, potash, alumina, silica.
Felspar	,,	potash, lime, soda, barium, alumina, and silica.
Apatite	,,	calcium phosphate.[2]

The action of water on the surface, then, has been to abstract nickel and iron, most of the magnesia, and to concentrate soda, potash, lime, and especially the silica. Let us first trace the main substances in the weathering of granite and see what becomes of them; we can then work back to the primitive rock surface of the globe, applying the same principles.

The silica is in the form of free crystallised quartz, and in combination with alumina, when it forms felspar, and with iron and magnesia, when it forms hornblende, augite, and black mica. The first, quartz, is practically insoluble in

[1] In meteorites the elements are differently arranged; they include such minerals as :—

Schreibserite	iron, nickel, cobalt, phosphorus.	Graphite	carbon.
Cohenite	iron, nickel, cobalt, sulphur.	Magnetite	iron oxide.
Troilite	iron, sulphur.	Tridymite	silicon oxide.
Oldhamite	calcium, sulphur.	Diopside	calcium, magnesium, iron, silica.

[2] This is the common phosphate, but monazite and triphyllite are by no means so rare as generally supposed in granite rocks.

water at the surface of the earth and is left behind as grains when the rock disintegrates; this is swept down into valleys by rain, and is carried by rivers to the sea as sand. The second, silicate of alumina, is also practically unacted upon by circulating water; it becomes hydrated and is left behind and washed down as mud into the valleys, and forms clay when deposited in the ocean. Sand, from the greater bulk of the grains, is deposited near the shore, though when buoyed up in water it is readily moved by inshore currents from one place to another owing to its low specific gravity. The mud, or hydrated aluminium silicate, is in the form of minute scales, which float readily in water, and are so minute sometimes as to form almost a solution. Such colloidal clay, as it is called, remains suspended for weeks in pure water and in practice has to be precipitated by alum if the water is wanted for drinking purposes; the limit to which the finest material is carried is 200 miles from the shore, and beyond this no deposits resulting from the disintegration of land masses are met with.

The last form in which silica is carried away is colloidal or jelly-like silica. It is this variety that forms all the flints, agates, cherts, and so on, and is present in sea-water in exceedingly minute traces, yet it is largely used by siliceous sponges and minute organisms such as radiolaria and diatoms to form their hard parts. In the soil it is taken up from solution by grasses in very large amounts, as may be seen by the slag of fused silica left behind when a hay rick burns.

Of the substances in solution the soda is conveyed direct to the ocean, where it remains dissolved and where it is probably increasing in amount. The source of original soda, however, is probably exhausted; there are no islands of the primitive rock nucleus of the earth left uncovered by later sediments and their metamorphosed equivalents, so that beyond a small amount received annually with meteorites, the salt in the rocks of the earth's crust is constant. It has been and is often fixed and taken out of circulation by the evaporation of large arms of the sea that have been cut

off by earth movements. Illustrations of this are familiar in the great salt deposits in North Germany, which were formed in Triassic times by the restriction of a great salt lake from connection with the southern ocean where the Mediterranean now lies. At other times, in the interior of arid regions whose water supply is insufficient to carry the rivers to the sea, the soda is arrested in lakes and pans, where, on the evaporation of the water, great masses of salt are thrown down. Instances of this are the Dead Sea and the Great Salt Lake of Utah, and the thousand and one salt pans which dot the dry uplands of South Africa. Salt seeps downwards in solution through the crevices in rocks and can be detected in almost every rock, no matter from how deep it may have been mined. But the essential fact to notice is that as soda comes out of combination in rocks the bulk of it travels outwards not downwards; there are large accumulations of salt on the surface of the globe dissolved in sea-water in contrast with the iron which goes into solution on the weathering of rocks but does not reach the sea.

Potash has a much more complicated rôle. It is jealously retained by soil, and is absorbed by plants growing on it; it clings to clays and becomes concentrated in them, and only a relatively small percentage escapes to the sea. In the great North German salt deposits, where millions of tons of sea-salt have crystallised under conditions which have allowed the various substances in solution to separate out, the deposits of potassium salts, sylvine, carnallite, polyhallite and so on, are enormous; but proportionately they are not great. The consequences of this peculiar circulation are that the potash is carried down in sediments, and when these are in course of time covered with other sediments and metamorphosed, the end product will be a granite containing felspar composed of potassium aluminium silicate, whereas the primitive types of rock contained felspar composed of lime-soda-aluminium silicate.

Lime has much the same circulation as soda, that is to say, it tends to escape the round of rock evolution from sediment

through gneiss to granite. It does so by becoming locked up in immense beds which form in the depths of the ocean, and though the lime is not in solution, it belongs like soda to the ocean and does not properly take its place among sedimentary deposits. The Archæan everywhere, notably in the great area of these rocks in Canada, Central Europe, India, Africa, and Australia, is characterised by the enormous development of limestone. It is to be remarked, however, that lime-carbonate is precipitated by organic agencies as fast as it is carried to the ocean; the amount chemically formed by evaporation and expulsion of the carbon dioxide is infinitesimally small, as compared with what plants and animals use up. For plants we have the calcareous algæ which make the oolite grains and which, in the forms of coccoliths, corallina, lithothamnium, girvanella and others, have built up banks of limestone equivalent to coral reefs. Among animals there are the following:—Globigerina and the host of free-swimming minute animals with calcareous shells which float about in mid-ocean and cause a continuous shower of dead shells to rain upon the sea-bottom; these form the loose limestones or chalk. Then there are corals busily making the limestone reefs on the shores of warm lands, such as the Barrier reefs of Australia and East Africa and the coral islands. Next, there are the hosts of shells, bivalves, and univalves; and finally the larger animals—fish and land animals—which make their bones of the carbonate of lime.

The fixation of carbonate of lime took place in recurring periods in the history of the world as far as we know it geologically. In the Archæan there is the most, and in the Silurian, Devonian, Carboniferous, Permian, Jurassic, Cretaceous times, there were interludes of enormous calcareous deposits, but always in lessening magnitude: large amounts are being fixed now in coral islands and in the Globigerina ooze in the oceans, but the present period will not be known so generally as a limestone period as, for instance, the Silurian or Cretaceous.

Why, then, do not the Archæan gneisses, which undoubtedly consist of mashed up and metamorphosed sediments, contain large percentages of lime? This is not an enigma raised purely on the particular explanation of the origin of the earth's crust which I have adopted here, but it is a difficulty which recurs in an inverse order with the iron, and to a less extent with the magnesia resulting from rock weathering, and the solution of the question is required, even if we assume the nebular or any other hypothesis as the correct one. As far as I have been able to work out the matter the solution lies in recognising that lime tends to pass upwards and outwards in the earth's crust, whereas magnesia, which replaces it most frequently, passes downwards. I must confess that I have not the materials for a complete statement of the facts, but there is no doubt that lime-carbonate is most unstable in the earth's crust, being replaced by dolomite or by iron ore or by silica, and the substance comes up to the surface in springs.

Magnesia is divided into two portions: one which goes through the same round as lime, and one which has a circulation like iron. In the first case the magnesia goes to the sea with the lime in the form of chloride and sulphate. It is useless to animals for the purpose of building up their framework, and hence it would tend to accumulate in the sea like salt; but there is a provision of nature whereby, when an animal such as a coral dies, of two parts of lime in its hard cup one is restored to the sea to be used by other animals and its place is taken by an equivalent of magnesia. This process, known as dolomitisation or production of dolomite, enables the excess of magnesia to be got rid of.

In the second case, magnesia travels downwards with the descending stream of water in the earth's crust; if it meets with lime compounds, it displaces the lime, which, for an equally mysterious reason, travels upwards with the ascending stream.

The following is a table of the amounts of magnesia and soda in fresh and weathered rocks[1]:—

[1] George P. Merrill, *Rock Weathering and Soils*, 1897, p. 209.

	Fresh (per cent in rock).	Weathered (percentage loss).
Granite—		
Magnesia	2.44	1.49
Soda	2.70	28.62
Gneiss—		
Magnesia	1.06	74.70
Soda	2.82	95.03
Syenite—		
Magnesia	.68	82.10
Soda	6.29	97.11
Diabase—		
Magnesia	7.38	61.37
Soda	1.98	95.37
Basalt—		
Magnesia	9.14	74.10
Soda	2.72	61.69

In sea-water the ratio of magnesia to soda is 6.209 to 41.234 or 1 to 6.6. Taking granite as the type of rock now representing the average composition of the surface of the globe, the magnesia and soda originally would be approximately equal, and with entire disintegration equal amounts of magnesia and soda should go to the sea; if we grant for the moment that the original surface consisted of more basic rocks, then the amount of magnesia that should have gone to the sea should have been very much greater than that of soda. Taking the case of granite, however, why is there such disparity between the amounts of magnesia and soda in solution in the sea? A small amount is locked up in dolomitised coral reefs, but taken as a whole limestones forming at the present day do not contain more than one per cent of magnesia.[1] Looking at the more ancient limestones which have been buried under sediments in the earth's crust, we find generally the older they are the more dolomitised they have become; then, again, limestones exposed on the land become gradually dolomitised along the joint planes by absorption of magnesia and the exchange of lime for magnesia. We find actually, then, instead of going outwards with the soda, the magnesia derived from rock weathering goes downwards; this accounts for the small amount of magnesia in the sea-water. Why it goes downwards is at

[1] Georg Forchhammer, "Bidrag til Dolomitens-dannelshistorie," *Oversigt over der Kongelige Danske Videnskab. Forhandlingar*, Copenhagen, 1849, p. 89.

present entirely a mystery; from an analogy with iron, one might suggest that the magnesium in the earth's nucleus exerts an attraction on the magnesium in solution and thus draws it downwards, but this attraction being less than that of iron for iron, part of the magnesium remains on the surface of the earth. In dealing with the work of underground water we shall refer to this subject again.

Working backwards, then, from present conditions to earlier ones: if magnesia is continually going downwards in the earth's crust and not outwards, then the rocks on the earth's surface in previous ages must have been ones with a higher percentage of magnesia, more basic ones that is to say, and the more basic they were the more rapid the descent of magnesia. We cannot imagine that dolomitisation was more active in the ancient seas in the limestones as they formed, because we find even Archæan limestones which have not yet been perfectly converted into dolomite. The action of solvent water, then, in the case of magnesia, allows us to suppose that originally the rocks exposed on the surface of the globe were ultra-basic rocks rich in magnesia, and that by the continual abstraction of this magnesia and its conveyance towards the centre of the globe there has resulted the exposure of rocks at the surface now which on an average are low in magnesia content.

Percentage of soda, potash, lime, magnesia, and iron in sea-water, North Atlantic (Tornöe and Schmelk).[1]		Average of element in Archæan Rocks.		Average of element in the crust, water, and air.
Sodium chloride	2.682			
Sodium carbonate	.0166			
	2.6986			
Sodium	1.14	Sodium	2.63	2.40
Potassium chloride	.747			
Potassium	.04	Potassium	2.35	2.35
Lime-carbonate	.002			
Lime-sulphate	.1395			
	.1415			

[1] H. Tornöe and L. Schmelk, *Report of the Norwegian North Atlantic Expedition*, 1876-1878.

Percentage of soda, potash, lime, magnesia, and iron in sea-water, North Atlantic (Tornöe and Schmelk).[1]		Average of element in Archæan Rocks.		Average of element in the crust, water, and air.
Calcium . . .	·05	Calcium .	3·50	3·25
Magnesium chloride .	.3561			
Magnesium sulphate .	.2071			
	.5632			
Magnesium . .	.14	Magnesium .	2.62	2.35
Iron . . .	Trace *	Iron . .	4.64	4.2

* .000503 per cent in the Irish Sea in summer (Thorpe and Morton).[2]

The above list shows that soda is circulating freely; potash, however, which should show something like the same amount in the sea as soda, since the waters draining off the land are supplied by the rocks with nearly equal proportions, is in very diminished amount, that is, it is being laid by somewhere. Lime, likewise, is being locked up, so is magnesium, but both these leave an appreciable amount over for free circulation. Iron, however, which is in so much larger proportions in the earth's crust, practically disappears from circulation. What becomes of it?

Some of it is undoubtedly precipitated in lakes as iron ore by the bacterium *Crenothrix* and by the alga *Gallionella ferruginea*, Ehrenberg, and other portions in the laterite and ironstone gravels under the soil in hot climates and ill-drained areas, but the amount does not in any way represent the quantity weathered out of rocks and brought into solution in water. This certainly does not flow to the ocean, and it cannot evaporate into the air. Where does it flow to? It is sucked into the earth and seeks the centre.

It is not difficult to discover this iron on its way downwards. We have chalybeate springs like those of Harrogate, but the vast proportion of our spring waters are not ferruginous. In limestone regions, however, we can catch the mysterious substance in its flight, for the underground passages are often filled with iron ore in the form of hæmatite and bohn-erz or bean ore; this is iron oxide deposited by the water in exchange for an equivalent of lime-carbonate.

[1] H. Tornöe and L. Schmelk, *Report of the Norwegian North Atlantic Expedition*, 1876-1878.
[2] *Chemical Soc. Journal*, vol. xxiv. p. 507.

We saw in the table on page 60 that in diabase, when 100 per cent of the potash has been taken from the rock by weathering, 87.81 per cent of the iron has gone; that is to say, the magnesia having also practically all disappeared, the whole of the ferrous iron in the silicates has gone into solution, but the iron in the form of ferric oxide, magnetite, and perhaps combined with chromium and titanium oxides, has not gone into solution. Large quantities of titaniferous iron, chrome iron ore, and magnetite are carried undecomposed to the sea, and form deposits of black sand. Still we have to account for the 87.81 per cent of the iron in solution.

All sedimentary rocks are stained red, yellow, or blue with iron in the form of ferric oxide, hydrated oxide, or sulphide, so that some of the iron is held up like potassium attached to the grains of sand and kaolin of which such rocks are made. The proportion of iron oxide in sedimentary rocks is 6.49 for clays and 1.81 for sandstones; for this average Clarke has used 76 clays and 624 sandstones. The average for limestone is .66 in accord with the minute amount in sea-water; the number of analyses taken was 843.[1] Mellard Reade, working at the same problem, estimated the amount of substances removed in solution annually from a square mile of the earth's surface, on the average as follows:—

Amounts of Substances Removed in Solution Annually from the Surface of the Globe[2]

	Average per square mile.	Total for whole globe.
Calcium carbonate	50 tons	2,750,000,000 tons
Calcium sulphate	20 ,,	1,100,000,000 ,,
Sodium chloride	8 ,,	440,000,000 ,,
Silica	7 ,,	385,000,000 ,,
Alkaline carbonates and sulphates	6 ,,	330,000,000 ,,
Magnesium carbonate	4 ,,	220,000,000 ,,
Oxide of Iron	1 ,,	55,000,000 ,,
Total per square mile	96 tons	5,280,000,000 tons
Sir J. Murray's estimate *		4,975,000,000 tons

* *Scottish Geogr. Mag.* vol. iii. 1887.

[1] F. W. Clarke, "Analyses of Rocks made in the Laboratory of the U.S. Geol. Survey, 1880-1889," *Bull. U.S. Geol. Survey*, No. 168, 1900, p. 16.

[2] T. M. Reade, *Chemical Denudation in Relation to Geological Time*, London, 1879.

Pierre, however, gives for the amount of sodium chloride falling in the rain every year at Caen in France, per hectare as 37.5 kilogrammes, which works out at 9 tons per square mile.[1] I give this instance to show how difficult it is to estimate these factors.

To arrive at the amount of sediment I have taken the rate of the Mississippi basin as the average of denudation over the whole globe; other rivers like the Hoang-Ho and the Rhone have rates of discharge of sediment four times as great, but then the Hoang-Ho drains an exceptionally soft region of Loess and the Rhone is fed by mountain torrents; the Po drains away sediment at eight times the rate. The greater rates must be, however, discounted by the fact that there are many areas with no outlet to the sea, such as the Sahara and the north-west territories of the United States. The rate of discharge of sediment for the Mississippi indicates the withdrawal of $\frac{1}{6000}$ part of a foot per year, which, distributed over the whole globe, represents 1.7 cubic miles; taking sediment as 21 cubic feet to the ton we obtain 11,900,000,000 tons of material discharged in solution and as sediment into the sea per year. Murray estimates the total substances in solution as 4,975,000,000 tons, which, taken from the above aggregate, gives 6,925,000,000 tons of sands and muds.[2] 55,000,000 tons of iron oxide distributed through this would give a percentage of .79, as against an average of 6.49 per cent for argillaceous sediments and 1.81 for sands when converted into rock.

It is hardly fair to use these figures in an argument as there are so many uncertain factors in the estimate, but it enables one to put the question—"Where does the iron content of sedimentary rocks come from, seeing that the sea contains practically no iron, and the black sands consisting of iron ore are so heavy as to have an extremely restricted distribution near inshore?" The answer is that iron in solution is constantly being drawn by seepage into the deeper parts of

[1] J. J. Pierre quoted by Angus Smith in *Air and Rain*, p. 233.
[2] Sir J. Murray, *Scottish Geogr. Mag.* vol. iii. 1887, p. 76.

the crust, and many of the older rocks have been converted bodily into iron ores by this descent, while the layers nearer the surface are receiving proportionate amounts of the iron. We shall return to this point in discussing the work of underground water.

CHAPTER VI

THE SOIL

TO Liebig and the early investigators of the soil the processes of decomposition which obviously take place in it were the results of purely chemical actions. But the more the soil was investigated the more this explanation became untenable. There was discovered in it a teeming race of animals as well as of plants, of an order different from those which live upon the outer surface; a pigmy race, distinguished in the most essential characters from the larger forms which had been thought the only tenants of the globe. In these dwarfs, death resulting from disease and old age was unknown; the living substance of those which had their being in the Archæan and earlier times is still alive to-day. They could live without air, without light, in boiling water,[1] without food. Brought into existence to destroy, to break up the rocks of the primitive earth, to prey upon everything which came within their reach, many of them, when the earth became peopled with the higher animals and overgrown with the plants for which their activities had prepared the way, turned upon these usurpers and sought their annihilation. These microscopic pigmies of the underground world are the bacteria, moulds, fungi, blue-green algæ, myxomycetes, and the host of dreaded germs which plague us, our cattle, and our crops.

The main work of these organisms, however, is not to cause disease in the higher plants and animals, but to destroy and eat into the rocks. The soil primarily is not a medium on which to grow trees and herbs, but is the domain created

[1] 85° C. is the maximum temperature so far recorded, but the spores stand actual boiling.

by the activities of bacteria and other lowly forms of life for their own enjoyment; the higher plants exist by virtue of these, just as animals again live by virtue of the herbage.

The lower organisms which live in the soil, and belonging to the vegetable kingdom, are divided into the bacteria and true fungi and moulds. The following estimates are given by Ramann of the relative proportions in various types of soil:—

THE NUMBER OF THE BACTERIA IN THE SOIL (RAMANN)[1]

	In one gramme of the dry substance.	
	Bacteria.	Fungi.
Soil under pines with beech undergrowth	35,000,000	60,000
Pines in boggy ground with bilberry bushes	1,647,000	343,000
Beech leaf mould	31,000,000	560,000
Old leaf mould below beech leaf mould	264,000	800,000
Leaf mould in oak coppice	40,000,000	3,430,000
Pine needle mould	50,000,000	Uncountable
Loamy soil	4,860,000	4,000–277,000 *
Sandy soil	2,500,000	66,000–566,000 *
Soil below humus	247,000	35,000–350,000 *

* From one cubic centimetre.

These numbers seem enormous, but it must be remembered that the bacteria are very small, about one-thousandth of a millimetre in diameter, and their saturation point would only be reached when there were 600,000,000 in one cubic centimetre of soil.

The manner of estimating these is by growing cultures in gelatine or agar-agar, and then counting the developing colonies of bacteria; the results are approximate only, and there are doubtless immense quantities that do not germinate in the particular medium employed, while others, judging from the investigations into diseases, such as tetanus and lupus, are too small to be recognised under the highest powers of the microscope. It is possibly these ultra-microscopic bacteria, which, carried through space in meteorites, inoculate the dead

[1] E. Ramann, *Bodenkunde*, Berlin, 1905, p. 120.

worlds and start the cycle of organic life.[1] Another factor which increases the difficulties of estimation is the enormous powers of multiplication which these organisms possess. A bacterium divides into two once in thirty-five minutes; one bacterium, therefore, will have, at the end of twelve hours, four millions of descendants, so that the numbers vary from moment to moment.

While actual numbers cannot be given definitely, the proportions are more or less correct. It has been found that the bacteria are more abundant in the first foot or so of soil. Thus Adametz found in one gramme at the surface 38,000 bacteria, and in 10 inches there were 460,000, while in this particular sample there were only 40 to 50 fungus germs, of which six species were true moulds and four were ferments, including the yeasts of wine and beer.[2] At 3 feet the numbers decrease rapidly according to the aeration of the soil. Fraenkel found that even in the soil beneath the pavements of Berlin there were still considerable numbers at the depth of 8 to 10 feet.[3]

Bacteria predominate in cultivated lands, while the moulds are found in open meadow, under forests and in natural surface soil generally. It is the function of the moulds to keep the surface layer open; they send forth their filaments between the grains of sand and clay, push them aside and make channels for the entrance of air; they may be called Nature's tillers. In cultivated ground man ploughs and harrows the land so that an artificial tilth is produced far in excess of that in the natural soil, and crops grown on it are enabled to thrive without hindrance, whereas if the same seed were planted in the natural soil, which is just sufficiently aerated to support the indigenous flora, the germinating plants would be stifled.

The work of the moulds in another direction can be seen on the pine needle litter or fresh leaf mould, where the leaves are spun together by a web made of tender filaments of the

[1] Siedentopf, *Journ. Roy. Micr. Soc.* 1903, p. 573.

[2] Adametz, Inaug. Diss. Leipzig, 1876.

[3] E. W. Hilgard, *Soils in the Humid and Arid Regions*, New York, 1906, pp. 142-3; Fraenkel, *Zeitschr. f. Hygiene*, vol. ii. p. 521.

growing moulds, and decomposition goes on rapidly. Rostrup called this particular form of mould *Clodosporium humifaciens*, but there are doubtless many kinds at work, all active in breaking down the cellulose of plants into humus. It is this parasite and saprophytic action of the lower organisms that has overshadowed the importance of their other activities which are less obvious. Many species are certainly detailed specially to promote fermentation, putrefaction, decay in all its forms, in vegetable and animal tissues, but others have different work to do. Kunze has shown that the higher plants have roots, that, with the exception of carbonic acid and formic acid are incapable of breaking down the mineral substances which they absorb, and Kunze attributes the action to bacteria and moulds.[1] Nikitinsky, Czapek, and Kohn have shown that cultures of the moulds *Aspergillus niger* and *Penicillium glaucum*, when fed with ammonium chloride, set free hydrochloric acid which alone, and in the presence of nitrates, will dissolve most of the known minerals.[2]

Bacteria have principally been studied from the standpoint of disease in man and animals, but recently the attention of agriculturists have been directed to the nitrifying organisms. The first stage in the fixation of atmospheric nitrogen is accomplished by certain flagellate cells, belonging probably to the animal kingdom, called *Nitrosomonas*; and these, then, are succeeded by minute rod-like bacteria called *Nitrobacteria*, which oxidise the product of the former into nitrates. These latter live principally, or perhaps more properly should be described as having been detected living, in the root nodules of clover, peas, and similar leguminosæ—the *Rhizobium leguminosum* especially; but they are occasionally found in the roots of forest trees, and it is now recognised that bacteria with similar functions live free in the soil. The bacterium responsible for the formation of saltpetre in the soil in India has been isolated and named *Bacillus malabarensis*; a similar one in European soil has been found and named *B. danicus*.[3] Another

[1] G. Kunze, *Jahrb. wiss. Bot.* vol. xliii. 1906, p. 357.

[2] F. Czapek, *Progressus rei botanicae*, 1907, p. 436.

[3] F. Löhnis and T. Westermann, *Centralblatt f. Bakt.*, 1908, p. 234.

nitrifying organism is the *Azotobacter chroococcus* which lives on the leaves of trees and causes leaf mould to be so rich in nitrogenous substances.[1] Some of the bacteria, *e.g. Bacillus pyocyaneus* and *Vibrio denitrificans*, and some of the ferments also, have the power of undoing the work of these nitrifying bacteria; they denitrify and convert nitrates into free nitrogen and carbon dioxide. The fact is familiar to gardeners where this action is brought about by denitrifying bacteria in fresh stable manure, whereas in old manure these deleterious organisms are absent. Perhaps the best example, however, is in the modern method of the treatment of sewage: the waste organic substances are led into a septic tank where, after awhile, they are completely decomposed by the action of bacteria with the liberation of nitrogen and carbon dioxide, so that all that remains over is pure water.

Fritsch[2] has accumulated a vast amount of information on the rôle of the algæ growth in the colonisation of new ground; but the point which is most interesting in connection with the question under discussion is the fact that the blue-green algæ are able to live on the bare, sun-scorched ground, and derive their subsistence from purely inorganic sources. At Nalande in Ceylon, he found that the bare walls of the great water tank were first coated with red gelatinous algæ of the genera *Glœocapsa* and *Aphanocapsa*; they occupy every little crevice in the rock, giving its surface a red, granular, speckled appearance. These places serve as a centre for the growth of *Phormidium laminosum*, which develops huge thin papery films covering large portions of the rock-surface, and also for the filamentous growths of *Scytonema*, which cover the rock with a slippery tangle making ascent very difficult. In some cases the tangles of *Scytonema* were developed in the *Phormidium* as a base, or the latter bore tufts of *Tolypothrix*, often forming lumps with definite stratified layers.

We have already referred to the case of Krakatoa described

[1] A. D. Hall, *Recent Advances in Agricultural Science*, Addresses and Papers, Brit. and S.A. Assoc. for Adv. of Sci., Johannesburg, vol. i. 1905, p. 99.

[2] F. E. Fritsch, "The Rôle of Algal Growth in the Colonization of New Ground," *Geograph. Journal*, vol. xxx. 1907, p. 531.

by Treub where blue-green algæ, *Tolypothrix*, *Anabæna*, *Symploca* and *Lyngbya*, feed upon the pumice and volcanic ash and convert them into food for the higher plants.[1] Bohlin describes a similar growth on the volcanic rocks of the Azores.[2]

In Angola, Welwitsch has recorded a remarkable occurrence of algæ growth. At Pungo Andongo there are what are called the *Pedras Negras* or black rocks.[3] These owe their colour to the abundant growth of an alga, *Scytonema myochrous* var. *chorographicum*, which during the rainy season generates and multiplies so rapidly that in a very short time the upper portions of the mountains are covered with it. Soon after the hot season has set in, at the end of May, the black plantlets begin to discolour with the intense heat. They gradually become dry and brittle, until by and by they peel off entirely, after which the rocks lose their sombre dry aspect and reappear in their natural grey colour. In the sandy valley of the Cuanza River in the same country, Welwitsch describes another form of *Scytonema*, *Porphyrosiphon notarisii*, which extends over wide meadows, closely spread like a net over the soil. By reason of its hygroscopic nature it absorbs moisture during the dewy night, affording by this means a refreshing protection to the roots of the larger plants during the glowing heat of the day. Boodle has described from the deserts of Australia an even more vigorous growth of algæ: when the plants dry up their substance forms a crust resembling elastic bitumen, which is found covering large areas of the country; a similar deposit has been found in tropical Africa.[4] These instances are interesting geologically, as there has been a good deal of speculation as to the nature of the

[1] Treub, "Notice sur la nouvelle flore de Krakatoa," *Ann. Jard. bot. Buitenzorg*, vol. vii. 1888, p. 213.

[2] Bohlin, "Étude sur la flore algologique d'eau douce des Azores," *Bih. K. Svenska Vet. Akad. Handl.*, Stockholm, vol. xxvii. Afd. iii. p. 12.

[3] Welwitsch, *Journal of Travel and Nat. Hist.* vol. i. 1868; Fritsch, *loc. cit.* p. 543.

[4] L. A. Boodle, *Bull. Miscellaneous Information*, Kew, 1907, No. 5, p. 145; W. T. Thiselton Dyer, on "A Substance known as Australian Caoutchouc," *Journ. of Botany*, 1872, p. 103; J. R. Jackson, "Coorongite, or Mineral Caoutchouc of South Australia," *Pharm. Journ. and Trans.* 1871, vol. ii. p. 763.

plants which produced the beds of anthracite in pre-Cambrian times, such as occur, for example, in the Jatulian dolomites and sandstones where a bed 7 feet thick has been discovered at Olonetz in Finland;[1] the ability of fresh-water algæ to form beds of carbonaceous matter at the present day renders it possible to explain these occurrences without bringing in the higher plants.

These remarkable cases, however, are exceptions, perpetuating perhaps conditions which existed before the higher plants arrived on the earth; similar growths of blue-green algæ can be studied in any bare ground which is kept moist in any country. The presence of moisture is essential to the growth of algæ, and to overcome this difficulty many species have entered into partnership with fungi; the weft of the mycelium of the latter forms a coating for the algæ which protects them from desiccation during the day, and water can be absorbed during the night from the dew that falls. This symbiotic growth of algæ and fungi constitutes the lichens. The ability of lichens to grow on bare rock is of such common knowledge that it is hardly necessary to labour the point; any cliff-side or house-wall will have lichens growing upon it, breaking down the rock substances so that after a while grasses and weeds find lodgment. That the lichens do not merely cling to the wall and absorb nutriment from the air, but actually eat and digest the rock can be seen by the corrosion of the surface, or by the actual observation of the absorbed constituents of the rock in the form of crystals, such as oxalate of lime, in the cells.

The investigation of the microscopic animals of the soil is practically untouched. Müller has found *Difflugia*, a large fresh-water rhizopod, in bog-humus,[2] and we have already mentioned the case of *Nitrosomonas*. The intestines of worms swarm with Gregarines, which seem to play the same part with them as bacteria do with plants, and it is certain that many of these minute animalcules live in the soil and

[1] A. Mickwitz, *Bull. de l'Acad. Imp. d. Sci. d. St-Pétersbourg*, 1907, p. 609.
[2] P. E. Müller, *Natürl. Humus-Formen*, p. 27; E. Ramann, *loc. cit.* p. 121.

both creep into their hosts and are ejected by them in countless numbers. If a worm could be hatched under antiseptic conditions and then allowed to run wild for a time in the soil, it would soon become full of the various tribes of parasites with which the ordinary ones are infested, and there is every reason to believe that these forms were in the soil before ever a worm was there, and like bacteria, they have found hosts as these have developed in their turn. To illustrate this point further: the ferment of beer lives in the soil, and it lived there long before man came on earth to use it for his pleasure and profit. We must believe then that animal germs which are found in animals, the trypanosomes for instance which cause malarial fever, live in the soil in as great numbers as bacteria. They have no definite reactions, however, like bacteria, and they are too minute to separate individually. With the *Fuligo varians* (*Aethalium septicum*) the so-called flowers of tan, which spreads out into colonies a foot or more in diameter, we can be sure that the germs live in the natural bark of trees and in the mould underground. Though definite evidence is wanting, it is probable that microscopic animal life is as abundant in the soil as the bacterial and fungoid growths, but the study of it presents such insurmountable obstacles that it is doubtful whether we shall ever know much about it definitely.

With these investigations the study of micro-organisms in the soil stops as far as their absorption of inorganic substances is concerned. Micro-biology does not come within the range of geologists as a rule, and botanists and agriculturalists are not interested in the causes of the disintegration of rocks beyond the more obvious ones. They see, for instance, that a lichen growing upon a piece of felspar in a granite corrodes it; they see in the cells of the lichen minute crystals of oxalate of lime; what is simpler than to infer that the lichen has elaborated citric acid which has acted chemically on the felspar?

The whole plan of this book, however, is to let facts speak for themselves, and as far as possible to include all of them;

if we leave out some the explanations cannot be right. We know that every root or underground filament is surrounded with a film of water in which countless myriads of minute organisms live. The soil is swarming with bacteria, fungi, and other low organisms, and becomes sterile if weak solutions of carbolic acid or chloride of mercury are poured upon it. We shall now proceed to show that bacteria are known to act directly on inorganic substances and the inference follows naturally that a large part of the activities of the bacteria in the soil is concerned in the breaking down of rock substances.

The absorption of carbonate of lime by the lower organisms is well known. In plants the minute Coccoliths and Rhabdoliths, the blue-green algæ, *Chroococcus* and *Gleocapsa*, the larger red or calcareous algæ are examples, while among animals all the Protozoa and Sponges have genera which absorb and secrete carbonate of lime as one of the functions of their cells' activities. The action is perfectly simple; oxidation of the carbon in their protoplasm produces carbon dioxide, which acts chemically on calcium carbonate and forms a soluble compound. The formation of oolite grains is another instance; the collection of the carbonate of lime is supposed to be brought about by the thallus of an alga which encrusts the central grain, and grows, depositing as it does so the lime-carbonate in concentric layers. Certainly the larger encrusting red algæ act in the same way, but the living organism has never been actually observed in the oolite grains though nodules of lime-carbonate in fresh-water lakes are usually covered with blue-green algæ, *Gleocapsa*, etc. The same is believed to happen with the pisolites forming as pea-like granules as deposits from hot springs. The blue-green algæ are known to be able to live in hot water, but here again the actual organisms on the pisolites have not been seen, though Kohn asserts their presence. From the work of Wethered in England,[1] and Chapman in Australia,[2] it is

[1] E. Wethered, *Quart. Journ. Geol. Soc.* vol. xlvi. 1890, p. 270; vol. xlvii. 1891, p. 550; vol. xlviii. 1892, p. 377; vol. xlix. 1893, p. 236.

[2] F. Chapman on "The Relationship of the Genus *Girvanella* and its Occurrences in the Silurian Limestones of Victoria," *Australian Assoc. f. Advancement of Sci.*, Adelaide, 1907.

probable that the older limestones in the Silurian and earlier times owe their origin to one of the blue-green algæ, *Girvanella.*

On the other hand the destruction of oolite grains and shells generally is accomplished by boring algæ, such as *Hyella*, which send microscopic filaments through the hard calcite of which they are made, and cause them to crumble up. In this they resemble the fungi in the manner of growth, and Lind has in fact described fungi which have the same power of penetrating limestone and marble.[1] Boring sponges like *Cliona* do the same in the animal kingdom.

With silica the matter cannot be so easily explained. There are countless numbers of plants and animals which absorb and secrete silica, and the lower forms are usually closely allied to the lime-secreting genera. Among the siliceous plants there are the host of the Diatoms, and among animals the Radiolaria and Sponges.

In the case of iron the matter is not so clear. The bog iron ore which forms at the bottom of lakes and under the soil in marshy places, where it is known as Moor bed stone, Ortstein, or Oudeklip, is by many thought to be simply due to the action of chemical deposition. Organic acids certainly dissolve the iron, and when the solution is oxygenated carbon dioxide is given off, and the iron is deposited either as a carbonate or as a hydrate. In Nature, however, the precipitation goes on in the absence of oxygen, in the bottoms of lakes and in soil which is not properly aerated. Ehrenberg attributed the deposition to a diatom which he called *Gallionella ferruginea*, but there is also the iron bacterium *Crenothrix* at work.

When we come to the sulphates the evidence is clearer. There are definitely bacteria which feed on sulphur and separate it both as oily globules of the element and as sulphuretted hydrogen. The effect of feeding the bacteria of

[1] See A. Kölliker on "The Frequent Occurrence of Vegetable Parasites in the Hard Structures of Animals," *Ann. Mag. Nat. Hist.* vol. iv. 3rd ser. 1859, p. 300. J. E. Duerden, "Boring Algæ," *Bull. Am. Mus. Nat. Hist.*, New York, vol. xvi. 1902, p. 323; K. Lind, *Jahrb. wiss. B.* vol. xxxii. 1898, p. 603.

the soil with gypsum or hydrated lime-sulphate is most marked. Pichard states the fact in the following way: The nitrification in the soil by bacteria was stimulated by—

STIMULATION OF NITRIFYING BACTERIA IN SOIL BY THE ADDITION OF CHEMICAL SALTS (PICHARD)[1]

Magnesium carbonate	12	times proportionately
Calcium carbonate	13.3	,, ,,
Potassium sulphate	35.8	,, ,,
Sodium sulphate	47.9	,, ,,
Gypsum	100	,, ,,

In the case of the carbonates the action is probably simply due to the neutralisation of acids which act deleteriously on bacteria, but the action of sulphates is certainly direct and is due to their forming food-stuff for the organisms.

Though no direct evidence is as yet available as to the action of sulphur bacteria, *Beggiatoa*, in the soil, there are the researches of Zelinsky and Brussilovsky on the bacteria in the Black Sea, which leave one with very little doubt that the reaction with regard to sulphides and sulphates on the land is a similar one to that in the sea. The surface waters of the Black Sea contain free oxygen, and support an abundance of organic life; but the deeper and denser waters are charged with sulphuretted hydrogen, and the only organisms present are anaerobic bacteria. The amount of sulphuretted hydrogen increases with depth. At 100 fathoms there are 33 cubic centimetres in 100 litres, at 200 fathoms 222 cubic centimetres, and at 1185 fathoms 655 cubic centimetres. Several species of bacteria have been observed, but only one, *Bacterium hydrosulphuricum ponticum*, has been studied in detail. The bacterium possesses the power of liberating sulphuretted hydrogen, not only from organic matter containing sulphur, but also directly from sulphates and sulphites. All authors are agreed that the sulphates of the sea-water are acted upon, but there is some divergence of views as to whether all of it is due to bacterial action or whether some of it is of purely chemical origin. Changes of the opposite kind take place in the zone where water containing sulphuretted hydrogen comes into contact

[1] E. W. Hilgard, *Soils on Humid and Arid Regions*, New York, 1906, p. 147.

with that containing oxygen. This zone occurs at a depth of about 200 fathoms. According to Yegunov and Vinogradski there lives here a race of sulphur bacteria which derive the energy necessary for their existenee from the sulphur of the sulphuretted hydrogen.

The sulphur is separated in their cells in the form of soft oily globules, and the oxidation of this sulphur gives them the necessary vital energy in precisely the same manner as the oxidation of carbon in other organisms supplies it. I must express my indebtedness to the presidential address to the Geological Society by Dr. Teall for the above facts, and it was that work which led to the train of reasoning adopted in this chapter.[1]

The organic substance of plants and animals, the protoplasm, consists essentially of carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. We have dealt with the separation of all these by micro-organisms except the last. We know of no phosphorus-eating bacteria, but phosphorus exists plentifully in the soil, being derived from the mineral apatite, a calcium phosphate, which is an accessory mineral in practically all igneous rocks. Phosphorus is also an essential to the plants, indeed to all organic life; and the lack of phosphorus leads to want of tone and nerve energy, which has to be supplied artificially in animals by means of medicine and in plants by such manures as guano, basic slag, and so forth. The natural phosphates of lime and magnesia are readily soluble in all weak acids and are available directly to the plant roots, but if there is any hydrated oxide of iron present in the soil, there is formed a phosphate of iron which is totally insoluble; basic slag, for instance, which contains large quantities of phosphorus and iron, lies unaltered on damp fields with acid or sour reaction in the soil.

As previously stated, Kunze has proved that in many of the higher plants their roots do not secrete organic acids with perhaps the exception of formic acid, the only secretion

[1] J. J. Harris Teall, "The Anniversary Address of the President," *Quart. Journ. Geol. Soc.* vol. lviii. 1902.

being water containing carbon dioxide. Prianischnikoff found on growing peas, lupines, mustard, and buckwheat in sand containing aluminium phosphate, which like phosphate of iron is insoluble in carbonic acid, that there was a vigorous absorption of the phosphate by the plants. The conclusion he arrives at is that the breaking down of the insoluble substance has been accomplished by bacteria.[1]

In South Africa the central parts are dry, and along the river courses there are magnificent stretches of alluvium, which, however, can only be occasionally watered by floods or by artificial irrigation ; the soil is usually rich in phosphates, but in taking samples of the soil after a spell of drought they are found to be in the insoluble form. When, however, the fields are watered and brought under cultivation an analysis of the soil shows a high percentage of soluble phosphates. There may be other means of explaining this phenomenon, but the one which suggests itself to any one acquainted with the bacteria in the soil and their life history, is that the solubility of the phosphates is brought about by the action of bacteria. When the soil becomes dry and parched, the bacteria encyst or retire into minute horny capsules and their activities cease; then when water is supplied to them the capsules absorb water and burst, freeing the rested organism, which straightway starts propagating at the alarming rate which such organisms have been observed to do.

This explanation is founded on analogy, but then similar analogies have been proved to be actual facts in the case of carbon, nitrogen, and sulphur, and it is likely to prove so in the case of the last constituent of protoplasm, if, indeed, Prianischnikoff's experiments with aluminium phosphate have not done so. If it be so, then it is one of the most beautiful examples of how Nature preserves her most precious assets against the proper time; for had the phosphates been in a soluble form all through, then the first flood waters would have soaked through the soil and drained them away to the

[1] D. Prianischnikoff, *Bericht deutsch. bot. Gesell.* vol. xxii. 1904, p. 184.

sea, and there would have been none left for the plants and the animals which feed on the plants. What does happen is that the water soaks through the soil with phosphates in the insoluble form, and then, when the surplus has drained away, the moistened soil gradually develops soluble phosphates as the needs of the plants require.[1]

We come to regard, then, the organisms of the soil as the persistent inhabitants of the globe when it was still impossible for the higher animals and plants to live upon it. We can imagine the earth to have been in such a state as Treub found Krakatoa in 1886, after the great eruption, with the primitive rocks slimy with teeming microscopic life. Heat, which kills most organic beings, was no hindrance, as many of the blue-green algæ live in hot springs to-day. Food, as we understand it, they did not require, as the rocks directly supplied them with it. We can assert that plants originally formed, collecting their carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus from the meteoric material, and then, their oily secretions forming emulsions with water, creating, as Bütschli has suggested, the primitive animals which were to devour them. It is to the soil that we should look as the seat of the origin of organic life, not to the sea. In the soil there is possible that concentration of solutions without which a naked cell—for the first organic cells must have been without a tegument—could not have won individuality; in the sea the diffuseness of solutions is now counteracted by organic precipitation, but before the organisms existed, no primitive life could have been created in it.

[1] E. H. L. Schwarz, "Agricultural Geology," *Natal Agricultural Journ.*, Pietermaritzburg, 1907, p. 933.

CHAPTER VII

THE ATMOSPHERE

THE upholders of the Nebular Hypothesis assume that at one time the atmosphere consisted of all the volatile compounds and gases now found upon the face of the earth, including all the water. If we accept the Planetismal Hypothesis we have just to take the gases as we find them in the meteorites of to-day, cook them out, and analyse them; then those gases will represent the primeval atmosphere. This is a plain fact which our experience provides us, and necessitates no draft of credulity on theories which are built up of unknown factors.

Lord Kelvin,[1] Stevenson[2] and others have argued that there was probably a time, and a long time, as measured by geological standards, during which the atmosphere contained no free oxygen, and that the whole of the existing oxygen in the air has been separated gradually by vegetation. This was probably the case, looking at the subject from the point of view of the theory we are now discussing. Meteoric matter containing carbonaceous matter and volatile hydrocarbons was hurled upon the growing nucleus, where, on their flight being arrested, enormous heat was developed. Hence it is hardly possible that any carbon present would escape oxidation if there had been free oxygen in the atmosphere, which there probably was not. The actual percentage of carbon in meteorites is about 1 per cent and is distributed as solid hydrocarbons of the forms, according to Farrington, C_nH_{2n}, $C_4H_{12}S_5$, and $C_9H_8O_2$; in the gases carbon monoxide, carbon dioxide, and marsh gas; in the elemental

[1] Lord Kelvin, *Nature*, vol. lvi. 1897, p. 461.
[2] J. Stevenson, *Phil. Mag.* vol. i. (5th ser.) 1900, pp. 312, 399.

forms of graphite, cliftonite, and diamond; and as a carbide of iron, nickel and cobalt, cohenite. The gases are distributed in the following proportions:—

GASEOUS CONSTITUENTS OF METEORITES (FARRINGTON)[1]

	Iron meteorites.	Stony meteorites.
Hydrogen	63.00	17.55
Carbon monoxide	20.70	4.15
Carbon dioxide	8.12	71.66
Nitrogen	7.52	2.20
Marsh gas	.57	4.17

Wright adds free oxygen to this list from spectroscopic examination of the gases of meteorites, but the amount is small and is occluded in the stones.[2]

From what we gather from meteorites, therefore, it appears probable that the earth received very little, if any, uncombined oxygen, and that thus the early nucleus was enabled to retain the nickel-iron on the surface of the globe, unaltered by the processes of oxidation which now go on so rapidly. It follows as a natural result that the progressive silicification of the earth's crust could not proceed until vegetable matter had appeared upon it, and allowed the oxidation of the iron and its consequent solution and abstraction. Where it went to is subject for a subsequent chapter. Farrington, who pointed out that the composition of meteorites probably gave a rough estimate of the composition of the earth as a whole, suggests that in the case of the meteorites the relative excess of magnesium and nickel, and the scarcity of aluminium and calcium is due to the fact that iron meteorites are more easily detected and preserved than stony ones, and that the entire falls, could we collect them, would probably show a more near approximation to the constituents of the earth's crust. On the other hand the density of

[1] O. C. Farrington, *Journ. of Geology*, vol. ix. 1901, p. 394. Since this was written R. T. Chamberlin has published in the *Publication No. 106* of the Carnegie Institution a series of analyses of the gases contained in rocks and meteorites; the general average of the gases in the latter is much the same as in Farrington's list, only the carbon compounds are rated at slightly higher values.

[2] A. W. Wright, "Spectroscopic Examination of Gases from Meteorites," *Am. Journ. Sci.* vol. ix. (3rd ser.) 1875, p. 301.

the meteorites as a whole, as given by Farrington, works out an average of 3.69[1] as against 5.5 for the earth; therefore, though this factor may enter into the question in regard to the present falls of meteoric matter, when the heavier material has been swept up, it is certain that in the earlier stages of the earth's development the irons predominated over the stony meteorites to a larger extent than now.

The composition of the atmosphere at present is as follows:—

	By volume.	By weight.
Oxygen	20.91	23.115
Nitrogen	79.06	76.840
Carbon dioxide	.03	.045

I have left out the argon, krypton, xenon, neon, helium, ammonium chloride, nitrates, and so on, which are in minute proportions and do not concern us here.

The primitive atmosphere, assuming that the iron meteorites and the stony ones fell in the proportion of six to four, which gives roughly the present density of the earth, and accepting Farrington's analyses of the gases of meteorites to represent it, was—

COMPOSITION OF THE PRIMITIVE ATMOSPHERE

Hydrogen	44.82
Carbon monoxide	14.88
Carbon dioxide	33.53
Nitrogen	5.39
Marsh gas	2.01

This is a sufficiently mephitic atmosphere; it is not contended that this actually was the composition of the original atmosphere, but it indicates the nature of it. The point to be noticed is that two of the gases, hydrogen and carbon monoxide, are ones hungry for oxygen, and they form nearly 60 per cent of the whole. All the hydrogen will have had to have been converted into water and all the carbon monoxide into dioxide before any free oxygen could have existed. Arguing from this standpoint we have to ask: Could life have existed in such an atmosphere, and if not,

[1] O. C. Farrington, "The Average Specific Gravity of Meteorites," *Journ. of Geology*, vol. v. 1897, p. 127.

are there any inorganic processes by which, to begin with, oxygen could have been set free, and the hydrogen, at any rate, converted into water? The answer to the first, I think, is an unqualified no; as long as there was no water on the surface of the earth no organic life could have existed, since the presence of water is a condition of its existence. We have no right to imagine organisms of a different order from that which we now know, such as one, for instance, made up of oil, which we know came with the meteorites, instead of water, and deriving its life energy by the conversion of this into alcohol, according to reactions of the following nature:—

$$CH_4 + CO_2 + H_2 = C_2H_6O + O$$
$$C_2H_6 + 2CO_2 + 3H_2 = 2C_2H_6O + O_2$$
$$C_3H_8 + 3CO_2 + 5H_2 = 3C_2H_6O + O_3$$
$$C_nH_{2n+2} + nCO_2 + (2n-1)H_2 = nC_2H_6O + nO$$

That is to say, the first stage of organic life resulted in an ocean of alcohol and the rain poured alcohol and the rivers ran alcohol, and in this lived oily individuals who gradually prepared the way for the water drinkers; the partiality for alcohol in limited quantities is still inherent in some organisms and would be, on this supposition, a remnant heritage from earlier times.

Phipson has grown plants in an atmosphere of hydrogen and was thus able to oxidise all of it to water;[1] hence we might imagine a race of primitive plants doing the same in the primitive atmosphere.

Of course there is an almost infinite number of other organic carbon-hydrogen compounds that would effect the same end, and the paraffin series need not have been the starting point among the hydrocarbons. It might have been, for instance, the olefines C_nH_{2n}, which are also detected in meteorites. Such speculations are outside our knowledge, and we must seek the primary separation of free oxygen from inorganic causes.

Of these the most natural is the absorption of carbon by iron and silicates in the form of carbides. We have actual

[1] T. L. Phipson, "Vegetation in Hydrogen," *Chemical News*, vol. lxvii. 1893, p. 303.

knowledge that such a reaction does take place by the fact that a carbide of iron, nickel and cobalt, named after Prof. Cohen, cohenite, exists in some meteorites. With great heat in a reducing atmosphere the formation of carbides would naturally take place, and heat being supplied by the impact of bolides and the reducing atmosphere only too much in evidence, it seems probable that the oxygen of the carbon monoxide and carbon dioxide was in this way primarily liberated. But the marsh gas would equally serve the purpose, and if this was used up in the carbide formation then an enormous additional amount of hydrogen would have been liberated. Carbides of the iron metals, of calcium, magnesium, and silicon (carborundum) may possibly have been formed sufficiently to supply all the hydrogen with the necessary oxygen to form water, but after that stage, any additional carbidisation would have resulted in the liberation of free oxygen ; the atmosphere would have begun to be an oxidising, instead of a reducing medium, and the reaction, therefore, could not have gone on. All the while that the carbides were forming, the surface of the earth must have been kept at a white heat, otherwise water would have condensed and the carbides of lime and magnesia would have been converted into acetylene and lime and magnesia.

The oxidation of the hydrogen, then, could be accomplished in this manner, and the whole amount precipitated as water. Once that had taken place the atmosphere was capable of supporting organic life. The further reduction of the oxides of carbon would naturally follow through the activities of lowly forms of vegetation, and thus the way prepared for the higher plants and animals.

I have left out the possible rôle of nitrogen in this connection ; under the violent conditions which were in operation on the surface of the earth during the early stages, it is quite possible that this inert gas was galvanised into activity, and the formation of cyanogen compounds took place, represented in its simplest form in the following equation:—$CO_2 + N + H = HCN + O_2$.

With this beginning all the cyanides, amines, sulphocyanides, albumenoids, alkaloids, etc., could follow, and in fact must have developed, to some extent at least, in order for primitive life to have begun, since combined nitrogen is necessary for their existence. It is, however, useless to pursue the subject as we cannot rely upon any facts to guide us; that some nitrogen was combined we can be sure of, but how much it is not possible to estimate but what there was added to the possible sources of free oxygen in the atmosphere.

The combination of iron and carbon need not have been a chemical one but may have been simply a mechanical one. Most of the iron meteorites show when their substance is dissolved a residue of minute scales of graphite, or octahedra of diamond, or the little pseudomorphs of graphite after diamond called cliftonite. If, however, iron meteorites were hurled upon the earth in immense masses and melted up by the impact in an atmosphere of carbon dioxide, the absorption of carbon is likely to have gone on to a larger extent. Iron melted in a furnace, where the combustion of the coal gives off an atmosphere comparable to the primitive one we have been considering, absorbs large quantities of carbon, and this crystallises out in cast iron. Moisson has, by suddenly quenching the white hot mass of molten iron in water, obtained sufficient pressure to crystallise this carbon as diamond.

Both combined and included carbon are found in meteorites, so that both probably existed in large quantities on the surface of the primitive earth, and the inclusion of carbon in the iron was one of the processes by which oxygen was liberated.

The occlusion of free oxygen and combined water in meteorites is not entirely ruled out; analyses do give both, but the former in very small quantities. In the case of water it is probable that the amount found by Mingaye in the analysis quoted previously (p. 40) was absorbed from the earth's atmosphere after the fall of the meteorite, just as the Spiegel River melilite-basalt obtained its water, if meteorite it be.

The free oxygen, after all the hydrogen and carbon monoxide were satisfied, had no free field left for its development, but was constantly sought for and stored away in the oxides of the various elements which formed the surface of the primitive earth. Of these processes it will suffice to follow that of the abstraction of oxygen by iron, which has been ably dealt with by Van Hise[1] and Smyth.[2] The latter in a succinct paper discusses the question whether there has been a progressive oxidation of iron since the beginning of geological time involving an abstraction of oxygen from the atmosphere. Taking Clarke's estimate, the older crust of the earth contains 2.63 per cent ferric oxide, Fe_2O_3, and 3.52 per cent of ferrous oxide, FeO. The analysis of Gilbert's samples, by Stokes, gave for shales 4.03 per cent of Fe_2O_3 and 2.46 per cent of FeO. For sandstones the figures are 1.24 per cent Fe_2O_3 and 0.57 per cent of FeO. By combining the figures for shales and sandstones, we have, as an expression of the iron contents of the sedimentary rocks, excluding limestone, 2.64 per cent of Fe_2O_3 and 1.52 per cent of FeO.[3]

Comparing these figures with the amounts found in the rocks of the older crust, the contrast is pronounced. In the older crust the ferrous oxide is in excess, while in the sediments the ferric oxide is markedly preponderant. This relation is expressed in the following ratios:—

In the older crust . .	$FeO/Fe_2O_3 = 3.52/2.63 = 1/0.75$ or 1.33
In sediments . . .	$FeO/Fe_2O_3 = 1.52/2.64 = 1/1.75$ or .57

In other words, in the older crust there is about three-fourths as much ferric as ferrous oxide, while in the sediments there is about one and three-fourths as much. Corresponding ratios for the two chief groups of sediments are as follows:—

Shales	$FeO/Fe_2O_3 = 2.46/4.03 = 1/1.64$
Sandstones	$FeO/Fe_2O_3 = 0.57/1.24 = 1/2.17$

[1] C. R. van Hise, "A Treatise on Metamorphism," *U.S. Geol. Survey Monographs*, vol. xlvii. 1904, p. 950.

[2] C. H. Smyth, "The Abstraction of Oxygen from the Atmosphere by Iron," *Journ. of Geology*, vol. xiii. 1905, p. 319.

[3] F. W. Clarke, *Bull. U.S. Geol. Survey*, No. 168, p. 14.

The small amount of iron in limestones does not materially affect this result, as also the relative small proportion of limestones to other sediments, Gilbert estimating them at one-fifth[1] and Mellard Reade as one-tenth.[2] The shales, sandstones, and limestones represent in altered form the materials of the old crust; the two latter show a decrease of iron while the shales show no increase. Making an allowance for concentration of iron in ores and other highly ferruginous rocks, it is probable that 4 per cent is a moderate estimate of the total oxidised iron of sediments, excluding limestones, and it is assumed that the ratio between ferrous and ferric oxides is that stated above, derived from Stoke's analyses.

To determine the amount of oxygen combined with iron in sediments, Joly's estimate[3] of the mass of siliceous sediments is taken as the amount of shales, sandstones, and ferruginous rocks.

THE AMOUNT OF OXYGEN ON THE EARTH

Total siliceous sediments . .	640,000,000,000,000,000	metric tons
Total iron	25,600,000,000,000,000	,,
Total oxygen combined with iron . .	9,600,000,000,000,000	,,
Total oxygen in old crust do. . .	8,765,000,000,000,000	,,
Difference of oxygen	835,000,000,000,000	,,
Amount of oxygen in atmosphere to-day	1,213,000,000,000,000	,,

The last but one figure, the difference between the amount of oxygen combined with iron in later sediments, as against the amount in older ones combined with iron, assuming the proportion of ferrous to ferric oxide to be that given above, is a measure of the amount of oxygen abstracted from the atmosphere since sedimentation in its ordinary sense began, and works out at 68 per cent of the amount of the oxygen at present free in the atmosphere.

It is hardly fair to use these figures in the argument, that, because there is less combined oxygen in the iron compounds of the older rock, therefore there was less available oxygen; or that the greater proportion of iron in the older crust shows that there was still a large amount of the original iron of the

[1] G. K. Gilbert, *Am. Geologist*, 1894, p. 214.

[2] T. Mellard Reade, *Chemical Denudation in Relation to Geological Time*, 1879, p. 53.

[3] J. Joly, *Sci. Trans. Roy. Soc. Dublin*, vol. vii. ser. 2, p. 46.

primitive surface which had to be got rid of, but it is interesting to notice that the facts derived from this calculation are not adverse to the theory we are discussing.

Assuming that the primitive surface consisted of free iron on the proportion to silica of 6 to 4, then there was an enormous field for the absorption of free oxygen. The conversion of metallic iron into oxides, carbonates, and other soluble forms was the process by which the gradual rise of the silica percentage in what became afterwards the crust, was accomplished.

Since sulphates are not known in meteoric material, but sulphides are plentiful, it follows that sulphates which exist on the earth in the form of gypsum, epsom salts, and so forth, must have derived their oxygen from the atmosphere. The amount of sulphur combined in sulphates in the ocean is estimated by Dittmar as 1187 billion metric tons; the oxygen required to form the sulphates would therefore be 1777 billion tons, or 145.25 per cent of that now in the atmosphere, that is to say about half as much again. To this must be added the sulphates existing locked up in deposits on the land derived from the evaporation of portions of the ocean in earlier times; Van Hise estimates these as 10 per cent of those now in solution; the percentage of oxygen combined in the sulphates must therefore be raised to 159.77 per cent of that in the air to-day. If we derived our sulphates from the oxidation of iron sulphides with the production of ferric oxide we shall have again to add one-fourth, making the total 199.91 per cent, or twice as much oxygen as now exists in the atmosphere; but this fourth we have already estimated for in dealing with the oxidation of iron.

Supposing all the water on the earth has been derived from the hydrogen brought to it by meteorites taking Van Hise's figures, we find, allowing oxygen 85.79 per cent and hydrogen 10.67 per cent, of the ocean water :—

Weight of ocean water . .	1,322,355,000,000,000,000	metric tons
Weight of oxygen . . .	1,134,448,354,500,000,000	,,
Weight of hydrogen . . .	141,095,278,500,000,000	,,

or about 635 times the amount of the oxygen in the air

to-day. The fixation of the oxygen by iron and sulphur, therefore, was a small affair as compared with the original fixation by hydrogen. I am aware that there are many pitfalls in this simple explanation; for instance, Chamberlin has doubted whether free hydrogen could have remained long on the surface of the earth, the kinetic energy of the molecules being greater than that of the earth's attraction; if that is so, then we must fall back on a longer process, imagining first a combination of the hydrogen with the carbon and production of carbon hydrogen compounds, then reduction of these to water. We cannot reconstruct, yet awhile at least, the intermediate stages of these chemical changes, but the beginning and end of the reactions seem fairly clear.

In the estimate of the composition of the original atmosphere, taking Farrington's analyses as a basis, carbon monoxide and dioxide represented 47.62 per cent of the whole; carbon dioxide now forms on an average three volumes in 10.00 or .045 per cent by weight; the relative volumes of the two atmospheres cannot be even guessed at, so that it is impossible to state the original amount of carbon dioxide. The amount at present in the atmosphere is:—

2,381,400,000,000 metric tons (Letts and Blake) (see note [1], p. 101)
2,277,000,000,000 ,, (Dittmar) (see note [2], p. 101)

In the various rocks analysed by Clarke the following ratios are given:—

AMOUNTS OF CARBON DIOXIDE ON THE EARTH (VAN HISE)[1]

	Percentage of carbon dioxide.	Percentage of rock among sediments.	Amount of carbon dioxide (metric tons).
Shales	2.64	65	11,583,000,000,000,000
Sandstones	3.03	30	6,135,750,000,000,000
Limestones	38.58	5	13,020,750,000,000,000
Total in rocks			30,739,500,000,000,000
Total in air			2,381,400,000,000
Total in ocean			96,531,915,000,000
Grand total			30,838,413,315,000,000

[1] C. R. van Hise, "A Treatise on Metamorphism," *Monograph U.S. Geol. Survey*, vol. xlvii. 1894, p. 965.

which makes the amount of carbon dioxide estimated to exist on the globe as about 13,000 times that at present in the atmosphere. In other words, if all the carbon dioxide were free the mass would be about 5.8 times that of the entire atmosphere as it exists to-day.

These estimates show succinctly what a vast amount of clearing the atmosphere has undergone, and the calculations, which are probably correct in the orders of magnitude, again show that the assumption of an original atmosphere composed of the gases distilled out of meteorites is borne out by them.

Directly the water was allowed to settle on the earth organic life probably started, and with the inception of that, there commenced the breaking down of carbon dioxide into carbon and oxygen. It is one of the arguments that we shall use in including in the list of sedimentary rocks the gneisses and metamorphic rocks generally, and even the granites, indeed all rocks with a high silica percentage, that this carbon separation began during their formation, for carbon is a frequent constituent in all these. It is impossible to estimate the amount of carbon in the earth's crust to enable one to calculate the additional amount of carbon dioxide which we must add to that already accounted for, in order to arrive at the ultimate grand total in the primitive atmosphere. The amount of coal can be roughly estimated, but then far more free carbon exists in the rocks in the coal measures and in carbonaceous shales, limestones, and sandstones, than will ever be economically worth while estimating. Right down to the earliest sediments carbon exists, becoming, generally speaking, more graphitic as we go towards the older beds. A 7-foot seam of anthracite has been found by Mickwitz in the Jatulian pre-Cambrian rocks of Finland. Though many have thought that metallic carbides are responsible for the production of some of this, the vast majority believe it to have been the result solely of vegetable or animal growth,

[1] E. A. Letts and R. F. Blake, "The Carbonic Anhydride of the Atmosphere," *Proc. Roy. Dublin Soc.* vol. ix. 1900, p. 172.

[2] W. Dittmar, *Report of the Voyage of H.M.S. Challenger*, 1873-76, "Narrative of the Cruise," vol. i. pt. 2, 1885, p. 954.

and therefore derived from the carbon dioxide of the atmosphere. Our reasoning on the first clearing of the carbon dioxide and liberation of oxygen, by the absorption of carbon directly by inorganic processes, forces us at present to keep an open mind between the two theories; we can imagine a sub-crust under the siliceous rocks having bands and layers of carbides just as in the crust itself we have beds of carbonates (limestone and dolomite). Certainly these original carbides must be now buried by immense thicknesses of rocks 30 miles or so, and it is doubtful whether under that pressure they could have been brought within moderate reach of the outer surface of the globe during geological time as measured by the rocks now exposed on that surface.

CHAPTER VIII

THE WORK OF UNDERGROUND WATER

THE work of underground water is usually understood to be concerned with the solution of substances in the positions of pressure and deposition in the positions of less pressure; that is to say, I accept Sandberger's work [1] in this connection as modified by recent researches. Posepny emphasizes the transporting power of water as distinct from simple transmission of material from one portion of the earth's crust to a neighbouring one,[2] but Posepny looks only on the ascending stream of water within the crust. To this we have to add the transporting power of water in the descending stream, one which is as important almost as the surface transport by rivers, and very much more important than the reassentional stream.

The solution of minerals in positions of pressure and the deposit of dissolved substances in positions of less pressure.

In all physical problems relating to geology we find that Daubrée has led the way in attempting to solve them. This investigator took for his rock experimented upon the most easily soluble one that is at all widely distributed, namely, limestone, and it is a fair inference that what happens in the case of limestone at ordinary temperatures and pressures during the time available in laboratory experiments, the same will happen in refractory rocks under great pressures, at high temperatures and with unlimited time. Daubrée took two spheres of limestone and rested the one on the other, the

[1] Fridolin Sandberger, *Untersuchungen über Erzgänge*, Wiesbaden, 1885, 1st Heft, p. 23.

[2] F. Posepny, "Genesis of Ore Deposits," *Trans. Am. Inst. Min. Eng.* vol. xxiii. 1893, p. 197.

upper of the two exerting a pressure of ten kilogrammes on the lower at the point of contact. A small amount of slightly acidulated water was allowed gradually to drop on to the upper sphere, which was quickly drawn to the point of contact and the limestone there became absorbed; in this way the centres of two spheres approached each other.[1]

In Nature this effect is seen to have been produced in beds of limestone pebbles in the Nagelfluhe in Austria[2] and in the smaller oolitic grains where pressure has been exercised upon the deposit, as Chapman has shown in the Devonian oolites of Ilfracombe.[3] Exactly the same happens in conglomerates with quartz pebbles; the pebbles in the more recent and looser conglomerates show cups and hollows where they impinge against each other, quite comparable to the hollows produced by Daubrée's limestone balls. In the older conglomerates, especially where the matrix is compact and therefore able to transmit pressure more evenly, the pebbles are wholly transformed, being flattened in the direction of pressure as if they had been so much putty, and even, as M'Callie has illustrated, may be drawn out in long fingers in the direction of flow of the yielding rock.[4] These phenomena are familiar to all field geologists; a granular quartzite under pressure has the grains rearranged so that they are flattened perpendicularly to the pressure, and where we look to the other minerals in a belt of pressure, such as the micas, hornblendes, and so forth, the fact is so apparent that the rocks derive their name from the schistosity produced by this rearrangement.

Barus found that water, under pressure and at a temperature of 180° C., contained in capillary tubes of glass decreased very markedly in volume, and this decrease went on at a

[1] A. Daubrée, "Cailloux impressionnées," *Études synthétiques de géologie expérimentale*, Paris, 1879, pp. 382-4.

[2] A. Heim, *Mechanismus der Gebirgsbildung*, Basel, 1878, atlas, pl. xiv. fig. 12.

[3] F. Chapman, *Geol. Mag.* vol. x. 1893, p. 100, pl. v. fig. 2.

[4] S. W. M'Callie, "Stretched Pebbles from the Ocoee Conglomerate," *Journ. Geol.* vol. xiv. 1906, p. 55; "Some Notes on Schist Conglomerate occurring in Georgia," *Journ. Geology*, vol. xv. 1907, p. 478.

FIG. 5. CRUSHED BOULDER, ENON CONGLOMERATE, WORCESTER, CAPE COLONY

FIG. 6. ENON CONGLOMERATE, GEORGIDA, UNIONDALE, CAPE COLONY

A sandstone naturally enlarged. The solid deformation of the pebbles is shown specially in the large one with the dent, on the right.

fairly uniform rate the longer the conditions were maintained. On examining the tubes he found that a considerable quantity of glass had been dissolved and redeposited in a crystallised condition. As the crystalline state is one of a closer packing of the molecules as compared with glass, the apparent decrease in volume in the water was thus explained. Below 180° C. this effect did not take place, but above that temperature the solution and crystallisation went on very much more rapidly, far more so than proportionally to the increase of temperature. The control of experiments of this kind at enormous temperatures is extremely difficult, and no general rules could be obtained for the solubility; but it is probable that the solution of silicates goes on at an increasing rate with increase of temperature, till it reaches a maximum of 365° C., when the molecule of water becomes unstable. At this point, if not long before, it is probable that all rock-substances are dissolved.[1] Taking one-tenth of the rate of solution of glass as representing the normal rate of solution of natural silicates, we find that water at 180° C. will dissolve and redeposit its own volume of minerals in five hours. If the volume of water in rocks is reckoned as .1 per cent of the whole mass, the rock at or below the level at which a temperature of 180° C. exists, could be dissolved and redeposited in 5000 hours or considerably less than one year. As a matter of fact, however, crystalline rocks on analysis give more than .1 per cent of water; some schists and gneisses go up to 2 per cent by weight or 5 per cent by volume, which means that they could be wholly recrystallised every 100 hours, or say once a week.

Taking the extremes in the rate of underground temperature as between 157.2 and 28.1 feet for every degree Fahrenheit, the temperature of 180° C. or 356° F. would be obtained at a depth of between 10.6 and 1.9 miles. If we add the pressure which the superincumbent rock exerts, then the lower figure is probably the maximum at which rocks could exist as

[1] C. Barus, "The Compressibility of Liquids," *Bull. U.S. Geol. Survey*, No. 92, 1892, pp. 78-84.

unaltered sediments, for pressure enormously increases the solvent action of water. In other words, no sediments could exist as limestones, sandstones, and shales below 1.9 miles depth in the earth's crust, but would be recrystallised as gneiss and granite.[1]

These estimates are borne out by actual experience. Dana estimated the thickness of sediments for continental areas as not exceeding 5 miles;[2] Mellard Reade originally estimated 10 miles, but later on he reduced his estimate to an average of 1 mile for the whole crust of the globe.[3] We shall return to this point in considering the composition of the crust of the globe which Mellard Reade estimated to be thinner in sediments in the ocean than in the continents, an estimate which we shall show reason for reversing. Judging from borings, however, and deep chasms in the earth's crust and by other means, it appears that the crystalline schists are never very deep at any part of the earth. Van Hise states that unaltered sediments frequently do not exceed 1 kilometre (.6 mile) and in general are less than 2 kilometres (1.2 miles) in thickness.[4] It is certain that the sediments have been many times as thick in these places, but the lower strata have been recrystallised at comparatively shallow depths.

Simple solution and redeposition is not by any means the sole work of underground water. Transport of the substances dissolved occurs as well, especially in a zone uniformly under pressure to a zone uniformly under less pressure. The fact is well seen in dykes of granite, where the materials of the granite wander into the slates adjacent and are deposited, not in the immediate vicinity of the dyke where the pressure is too great, but at some distance from it. The usual case is the transference of orthoclase felspar into the slate, and the

[1] E. H. L. Schwarz, "An Unrecognised Agent in the Deformation of Rocks," *Trans. S.A. Phil. Soc.* vol. xiv. 1903, p. 392.

[2] J. D. Dana, *Manual of Geology*, 2nd ed. 1875, p. 657.

[3] T. Mellard Reade, *Chemical Denudation in Relation to Geological Time*, pp. 29 and 52.

[4] C. R. van Hise, "A Treatise on Metamorphism," *Monograph U.S. Geol. Survey*, vol. xlviii. 1904, p. 939.

growth in the latter of crystals of felspar as "augen" or eyes between the foliæ. The most remarkable case of the kind I have come across is the transference of aluminium silicate from the granite to the schists at George in Cape Colony. With excess of potash the felspar ($K_2O, Al_2O_3, 6SiO_2$) forms in these slates adjacent to the dykes, but at one particular point, the potash is used up in the formation of muscovite or white mica ($K_2O, 3Al_2O_3, 6SiO_2, 2H_2O$) in the granite itself, and the aluminium silicate is alone available for carriage. In consequence the slates have great crystals of andalusite ($Al_2O_3SiO_2$) developed in them five yards from the contact.[1]

Then besides simple transference, there may be replacement of some constituent in the rock by material brought in from outside; the simplest form of this is the conversion of limestone into dolomite, where part of the lime of the original material is replaced by magnesia. This is not a mere casual replacement, but follows general laws which are understood and which can be used for quantitative estimations. Heat may be developed or absorbed during the process of rearrangement of the molecules; but without going into this, it may be stated generally that—

The volume of the original compound is to the volume of the compound produced, directly as their molecular weights and indirectly as their specific gravities (Van Hise).[2]

Taking in illustration the case of the dolomitisation of limestone, the molecular weights of limestone and the resulting dolomite are respectively 198.62 and 182.96; the specific gravities of the two minerals are respectively 2.7135 and 2.85. Then the compound proportion is—

$$V \text{ is to } V^1 \text{ as } \frac{198.62}{2.85} \text{ is to } \frac{182.96}{2.7135};$$

or V^1, the volume of the mineral produced by the replacement, is 87.70 per cent of the volume of the original mineral

[1] E. H. L. Schwarz, "The Andalusite Schist of George," *Records Albany Museum, Grahamstown*, vol. ii. p. 164.

[2] C. R. van Hise, "A Treatise on Metamorphism," *Mon. U.S. Geol. Survey*, vol. xlvii. 1904, p. 209.

V ; in other words, there has been a shrinkage of 12.30 per cent.

In the case of silica replacing carbon dioxide in limestone to form wollastonite, we have :—

	Limestone.	Silica.	Wollastonite.
Molecular weight	99.31	59.94	115.58
Specific gravity	2.7135	2.6535	2.85

Then the compound proportion is—

$$\frac{V^1}{V}=\frac{115.58}{2.58}\div\left(\frac{99.31}{2.7138}+\frac{59.94}{2.6535}\right)=.685\ ;$$

or the chemical reaction represented by the formula

$$Ca\ CO_3+Si O_2=Ca\ Si O_3+CO_2$$

results in a loss of volume of 31 per cent, the carbon dioxide escaping.

The replacement of silica by pyrites, which I have observed in rocks in South Africa[1] beginning with a mere layer of pyrites crystals under the surface of quartzite boulders in fairly recent sediments, such as the Triassic coal measures of Cape Colony, to the entire replacement of pebbles in the Archæan conglomerates of the Witwatersrand, results in an increase in the volume of the deposited mineral thus :—

	Silica.	Pyrites.
Molecular weight	59.94	119.26
Specific gravity	2.65	5.025

Therefore the compound proportion is—

$$V : V^1 :: \frac{59.94}{2.65} : \frac{119.26}{5.025}=22.6 : 23.7.$$

If marcasite were formed, the increase would be 2.98 per cent greater.

Thus we see that apart from pressure by the weight of

[1] E. H. L. Schwarz, "Note on a Quartzite Boulder from the Molteno Sandstone," *Records Albany Museum, Grahamstown*, vol. i. 1906, p. 341.

superincumbent strata and by contraction within the earth's crust, the actual molecular replacement of minerals may either accommodate the strain or relieve it. In the zone of weathering, oxidation and hydration usually result in increase of volume, and soft shales, such as we have in the Karroo, are thereby buckled up into folds from this process.

There can be no doubt of the solvent action of water on silicates with or without dissolved salts to increase the action; but high temperature and pressure and time are required for the process—if one or the other factor is absent then the silicates are unacted upon, but if there are more soluble substances in the rock, these will be absorbed and transferred to other parts, leaving the silicates more or less untouched. This is the principle of lateral secretion in the genesis of ore deposits as emended from the rather narrow limits defined by the originator, Sandberger,[1] by Emmons,[2] Becker[3] and others.

Starting with the silica in hot springs we find that while the water is hot and under pressure the silica remains in solution, but if this comes to the surface in geysers and hot springs, both the temperature of the water and the pressure are reduced and the silica comes out of solution and forms a sintery deposit round the orifice. Solution, then, is a function of temperature and pressure. Rocks in the earth's crust are under pressure; the water in the capillary and subcapillary interspaces is also under pressure, therefore it is capable of dissolving the rock substances and the minerals and ores contained in them. Split these rocks by means of a crack: the water charged with dissolved substances will be squeezed out of the rock into the open space and, pressure being relieved, the substances will be deposited. First and foremost the quartz is deposited in most abundance in deep fissures, as that substance forms by far the larger portion of

[1] Fridolin Sandberger, *Untersuchungen über Erzgänge*, Wiesbaden, 1875, Heft 1.

[2] S. F. Emmons, "The Genesis of certain Ore Deposits," *Trans. Amer. Inst. Min. Eng.* vol. xv. 1886, p. 125.

[3] G. F. Becker, "The Geology of the Quicksilver Deposits of the Pacific Slope," *Mon. U.S. Geol. Survey*, vol. xiii. 1888, p. 449.

all rocks on the earth's crust; hence in the older rocks we find quartz veins with the more insoluble substances, such as gold, contained in them. Nearer the surface, where the pressure has not been sufficient to keep in solution such refractory substances, the veins are filled on the same principle with sulphides and arsenides, and the gangue is calcite.

Sandberger at first examined the rocks as a whole, but later on analysed the crystallised constituent silicates such as olivine, augite, hornblende, and mica. With the exception of tellurium, gold, and mercury, which, from want of necessary appliances, were not looked for, all the elements usually occurring in metaliferous veins were found in appreciable quantities. Especially interesting in the present connection is the almost universal presence of nickel with a small amount of cobalt; iron, of course, occurs everywhere, but the general absence of nickel in veins except in peculiar situations where the rocks approach the composition of stony meteorites, leads one to suppose that, as in the case of iron, there has been a gradual reduction of the amount of this metal on the surface of the globe and a transference of it to deeper regions. The following metals were recognised by Sandberger in the respective silicates:—

Olivine . .	Iron, nickel, cobalt, copper.
Augite . .	Iron, nickel, cobalt, copper, lead, tin, zinc, antimony, arsenic.
Hornblende .	Iron, nickel, cobalt, copper, lead, tin, zinc, antimony, bismuth.
Black mica .	Iron, nickel, cobalt, copper, lead, zinc, arsenic, bismuth.
White mica .	Copper.
Lithia mica .	Copper, tin, arsenic, bismuth, uranium.

These results were obtained from crystalline rocks of every age including granites, gabbros, andesites, augite-porphyries, and basalts. The dolerites of the Witwatersrand contain appreciable quantities of gold, as I have myself found in assay, and there is no reason to except any of the metals from any of the crystalline rocks. Becker, in discussing the origin of the ores in the Steamboat Springs in Nevada, which

occur in fissures parallel to that in which the Great Comstock lode is situated, maintains that the evidence is overwhelming, that the cinnabar, pyrites, and gold of the quicksilver mines of the Pacific slope reached their present positions in hot solutions of double sulphides, which were leached out from masses underlying the granite and from the granite itself.

Sandberger limited the source of the minerals in veins to the rocks in the immediate neighbourhood, and thus left himself open to the attack of Posepny, who showed that a large amount of the material had come up from below. Suess has emphasized Posepny's opinion by saying that this water carrying minerals from below must necessarily be juvenile water, that is, water freshly disengaged from occlusion as oxygen and hydrogen in the molten interior of the globe.[1] But from what we have stated with regard to the circulation of water in the rocks, both Sandberger and Posepny are right if we take their theories together. Water is drawn down by capillary and molecular attraction into positions of great heat and pressure, dissolves the substances of the rock through which it passes, and reascends to the surface up any channel that lies in its path, depositing as it does so the various substances held in solution at the levels at which the release of pressure causes them to come out of solution.

I am aware that the whole subject of the genesis of ore deposits is one of much controversy. An investigator in one district will have his attention occupied with the evidences of igneous action, and will ascribe the ascent of mineral solutions to that agency; another equally competent will, in another district entirely free from igneous injections, have his attention drawn to other features; all may be right for their separate districts, but the rule for ore deposition accepted by a growing body of geologists surveying the whole field, is that given above. Deviations from it may occur in particular localities owing to special causes, but the details are not such

[1] E. Suess, "Über heisse Quellen, Vortrag gehalten auf der 74. Versammlung der Gesellschaft deutscher Naturforscher und Ärzte zu Karlsbad," 1902, *Prometheus*, vol. xiv. Nos. 690, 691, 692, Berlin, 1903; *Geogr. Journ.* vol. xx. p. 517.

as we can enter into here, and they do not affect the general principle.

Transport of material in descending water.

We have now to consider in some detail the water as it descends. We have already seen that it must carry an appreciable quantity of salt in solution, as crystals of salt are actually seen in the hollows filled in with water in the quartz grains of granite. Chlorides of iron and ammonia, again, together with hydrochloric acid are the invariable accompaniments of volcanic exhalations; this water must have come into the liquid rock of the volcanoes by absorption from the floor of the sea. Most geologists scout the idea that the water of the sea has won access to the molten rock, but their rejection of this assumption is based on the idea that the sea-water travels down actual cracks and fissures. If we replace these open spaces for sub-capillary passages, I can see no objection to the explanation. The salts contained in sea-water are exhaled, either actually, or transformed into new combinations, by volcanoes; and with sub-capillary absorption, this sea-water could be brought up by volcanoes on the borders of the continents near the ocean, or in the centre of Tibet, far away from it.

The iron in solution is, however, our most puzzling point; it is not found in appreciable quantities in sea-water, yet water running off the iron-impregnated continents is always pouring into the sea. Silica in very minute quantities escapes to the sea in solution, but then pelagic deposits of enormous extent are being formed by the silica-secreting organisms, diatoms, and radiolaria; there are no corresponding iron-secreting organisms in the sea, nor are there pelagic iron deposits. Manganese nodules dredged up from the abyss of the ocean frequently show on being broken open a central kernel of metallic iron, but this nucleus is almost certainly a little meteorite; iron of this nature is of extreme rarity on the sea-floor.

For the matter of iron we have the magnificent work of the American geologists in the Lake Superior iron ores to

guide us ; in dealing with this subject I have taken principally the work of Van Hise and Bayley.[1] The iron ores there occur in a threefold system, consisting of magnetite and hæmatite schists and jaspers. In South Africa the same three formations occur in the same order, but repeated four times, a fact which has led to endless confusion in correlation, and which is still the outstanding difficulty in South African stratigraphy. In India the same three series occur in the same order in the Transition system, and the same occurs in Australia and elsewhere. There are many theories as to the origin of the concentration of the ores, from contemporaneous deposit to volcanic ejactamentation, but these theories, however ingenious they may be, must give place to explanations which rely, step by step, on actual experience.

The genesis of the iron ores can be studied in its simplest form in the carboniferous limestone of Northumberland, Cumberland, and Durham. The ore there fills fissures and lake-like basins in the rock, sometimes immediately below the Glacial Drift, while at others it is found in an irregular form deep down in the limestone. At Bigrigg, Crowgarth, and Parkside, it occurs in large irregular masses in the limestone immediately under the Millstone Grit, one of the beds of which forms in each case the roof of the deposit.[2] It is usually conceded that originally the ore was deposited in the form of carbonate of iron; a solution of this in water, containing carbonic acid, on coming in contact with limestone deposited the carbonate of iron and carried away an equal volume of carbonate of lime ; the carbon dioxide was then removed by solution in water as the pressure developed, and as a result hæmatite was left behind. The evidence of this action is afforded by the fact that many carboniferous fossils, once

[1] C. R. van Hise, "Principles of North American Pre-Cambrian Geology," *Sixteenth Ann. Rept. U.S. Geol. Survey*, Pt. II. 1896, pp. 743-843 ; C. R. van Hise and W. S. Bayley, "The Marquette Iron-bearing District of Michigan," *Mon. U.S. Geol. Survey*, vol. xxviii. 1897 ; W. S. Bayley, "The Menominee Iron-bearing District of Michigan," *Mon. U.S. Geol. Survey*, xlvi. 1904. A complete bibliography is given in the last.

[2] J. A. Phillips and H. Louis, *A Treatise on Ore Deposits*, 2nd ed. 1896, p. 247.

embedded in the limestone, now lie in the hæmatite ore in their original positions, and some of them have undergone the change into hæmatite. Kendall derives the iron from the shales and sandstones immediately above which have since been removed by denudation ; the percolation of water leached this out and in its descent replaced the limestone which it dissolved by the deposit of iron.[1] The extraordinary fidelity with which structures in the original limestone are reproduced in iron ore is everywhere apparent in such deposits ; the oolite grains, foraminifera such as Fusulina, cone-in-cone structure, are all repeated in hæmatite. Limonitic deposits are not so common as hæmatite, but they do occur as Bohn-erz or bean ore, but in this case the large amount of combined water produces such an expansion of volume that the iron ore has its own particular structure, and borrows none of those in the original rock.

The replacement of limestone by hæmatite at comparatively shallow depths prepares one to accept the replacement of siliceous rocks at greater depths and under correspondingly greater pressures and temperatures. From the distribution, association, and composition of the Lake Superior iron ores in the districts of Menominee, Gogebic, and Marquette, it is evident that the same action in the quartzites and jaspers has taken place as in the Cumberland Mountain limestone, that is to say, by deposit from descending waters flowing in definite channels. Portions are of fragmentary origin, the debris of older formations ; but these were enriched by the addition of hæmatitic material from some overlying stratum, from which it was dissolved by surface waters and transported downwards, finally being precipitated between fragmental grains of the original sediments ; Bayley describes the process of concentration as follows :[2]—Surface waters containing oxygen, descending through the rocks above, dissolved iron carbonates and silicates in or near the position of the original

[1] J. D. Kendall, "The Hæmatite Deposits of Whitehaven and Furness," *Trans. Manchester Geol. Soc.* vol. xiii. 1876, p. 231.

[2] W. S. Bayley, "The Menominee Iron-bearing District of Michigan," *Mon. U.S. Geol. Survey*, xlvi. 1904, p. 29.

compounds ; carbon dioxide was thus liberated and became dissolved in the descending waters, which then took up more iron salts. In their downward passage the waters were converged into trunk channels by plunging synclines, or were diverted into definite courses by the contact planes between adjacent beds or by zones of brecciation. At those places the iron-bearing waters, which necessarily must have taken circuitous routes, were intermingled with water which had descended directly from the surface, and which, therefore, had retained its oxygen or most of it. Here the dissolved carbonate was decomposed and the iron oxide precipitated. There were thus formed pseudomorphs of hæmatite in place of original ferruginous concretions, and immense deposits of ore were gradually built up in the troughs of synclines within the iron-bearing formation. Continued passage of water along the same channels cleaned the deposits by removing from them all deleterious substances.

The exploitation of these ores forms one of the romances of modern commercialism ; had there been no direct descending waters, where would the unoxidised iron solutions have gone to?

This question is a new one in my experience, and I can only answer it by saying that the iron must descend to below the siliceous sediments and be there deposited as metallic iron. Incidentally it may be noticed that although this concentration of iron ores occurs in exceptionally favourable places, the same process goes on universally, so that sediments become more highly charged with iron the older they are. Directly recrystallisation on a complete scale, however, goes on, indicating a free and uninterrupted mobility of the molecules of the constituent substances, the rocks again become low in iron content. That is to say, the older unaltered sediments are rich in iron, whereas the granites are poor in iron.

Is there any reason why iron in solution should go downwards in the earth's crust and not outwards to the sea? To this we can couple the question, Why do sediments

reduced to complete fluidity by metamorphism lose their iron content? The only answer that I can see that will satisfy the needs of the case is that the metallic core of magnetic iron draws to itself all iron in solution. There is only one magnetic oxide, magnetite, which never exists in solution. When compounds of iron are dissolved, they become ionised, that is to say, a certain amount is split up into metallic "ions" and acid "ions"; the iron in a free metallic state, though joined to other substances by loose bonds, can be attracted by the magnet. The great central mass of metallic iron must then exert a pull on the iron in solution, and this pull lasting over interminable myriads of years, yet ever persistent and unceasing, would gradually draw downwards the ions of iron as they became formed in the surface waters of the earth. In regard to the question of a similar clearing of iron from granite, it should be noted that Barus has found that rock magmas are electrolytes, that is, solutions in which ionisation takes place, and in which, therefore, free metallic substances can and do exist, so that the subtraction of iron from granite can in like manner be ascribed to the magnetic pull of the earth's core.

The same reasoning would apply to the case of nickel and cobalt, which are also magnetic, though to a less extent than iron. The great deposits of garnierite in New Caledonia, which could yield more nickel than the world has use for, are in ultra-basic rock which is strangely like the meteoric stones which we find scattered over the surface of the earth in small lumps. It is by no means an impossible theory to consider the New Caledonian nickel deposits to be portions of a gigantic meteor which fell long ages ago, and which by earth movements has been so crushed, folded, and incorporated in the rock systems adjacent, that it has all the appearance of an igneous dyke. Otherwise the nickel deposits of the earth are always negligible as compared with those of the other metals, and it is legitimate to consider nickel as having been washed down in solution to the attracting metallic nucleus of the earth. To the case of cobalt the same reasoning applies.

The work of underground water in the case of magnesia is less easy to understand. Magnesia has undoubtedly been washed out of the surface rocks, for we find that generally speaking the older the limestone the more it has been dolomitised. There is a constant abstraction of magnesia from the outer surface going on; a small portion only is carried away to the sea where it lies for the great part inert. The percentage of salts in the sea is taken as 3.7 per cent of the entire ocean, and of this 3.7 per cent, 6.2 per cent is magnesia, and lime is represented by 1.67 per cent; but the lime is constantly being used up and as constantly renewed, so that the magnesium compounds, although largely in excess of calcium compounds in the salts of the sea, have only attained this percentage as the result of long periods of accumulation. Some of the oceanic magnesia is used up in the dolomitisation of coral reefs, although Forchhammer states that, taking recent limestones as a whole, the percentage of magnesium is less than 1 per cent.[1] The same author analysed various hard parts of animals and found 0.5 per cent to 1 per cent in bivalve shells, less than .5 per cent in cephalopods, and in most corals less than .5 per cent, but in some the percentage rose to 2 per cent, and in one instance to 6.4 per cent. The total amount of magnesia fixed in deposits in the ocean, however, may be neglected. The assumption that sea animals of by-gone times were able to use up magnesia for their shells more readily than the present forms is purely gratuitous, and magnesia in the older limestones must have come there by secondary alteration. This alteration may begin directly the coral reef dies; for instance, Dana found in the raised coral reef at Metia, that 38 per cent of the limestone had been changed to magnesium carbonate.[2]

Perhaps the most conclusive evidence that the bulk of the magnesium salts do not run away in the river water to the

[1] Georg Forchhammer, *Bidrag til Dolomitens-dannelhistorie.* Oversigt over det k. Danske Videnskab. Forhandlingar, Copenhagen, 1849, p. 89.

[2] J. D. Dana, *Corals and Coral Islands*, 3rd ed. New York, 1890, p. 393.

sea is afforded by the salt pans in the interior of Cape Colony. These pans are shallow depressions in the veld into which all the surrounding water flows; they may be from a mile to twenty miles across, and are usually dry during the greater part of the year. They owe their existence to the fact that the small amount of rain that falls is not sufficient to flow away in definite river channels, but rests on the sand-covered veld and gradually forms an irregularly shaped pan. The water is seldom more than a couple of feet in depth, but when the fierce desert winds blow, the water may be heaped up at one side and the other may be quite dry. Where the rocks in the neighbourhood are dolerite or diabase, the resulting decomposition produces salts of lime and soda from the felspars, and magnesia and iron from the augites; the products of solution are washed down into the pan, where in time thick layers of salt accumulate with deposits of gypsum in the mud below. The salt is invariably pure, and the magnesia content is very slight indeed. On the other hand, wells and springs tapping underground water in these regions are often bitter with magnesium sulphate, as many a thirst-stricken caravan has learnt to its cost.[1]

The salts in sea-water are :—

PERCENTAGE OF SALTS IN SEA-WATER (DITTMAR)[2]

	Per cent.	
Chloride of magnesia	10.878	
Sulphate of magnesia	4.737	
Bromide of magnesia	2.217	
		15.833
Sulphate of lime	3.600	
Carbonate of lime	·345	
		3.945
Chloride of sodium		77.758
Sulphate of potash		2.465

In Clarke's 1900 estimate the proportion of magnesium and sodium in the earth's crust is 2.62 and 2.63[3]; one would

[1] C. J. Juritz, "The Composition of Salt from some Colonial Salt-Pans," *Agric. Journ.* Cape Town, November 1908.

[2] W. Dittmar, "Composition of Ocean-water Salts," *Narrative of the Cruise of H.M.S. Challenger*, vol. i. pt. 2, 1885, p. 954.

[3] F. W. Clarke, "Analyses of Rocks, Laboratory of the U.S. Geol. Survey, 1880-1899," *Bull. U.S. Geol. Survey*, No. 168, 1900, p. 15; in the previous estimate, *Bull. U.S. Geol. Survey*, No. 78, 1891, p. 39, the proportions were $Mg=2.68$, $Na=2.36$.

hardly expect, therefore, such a disparity in the proportions of them in the salts in sea-water where, reckoned as elements, magnesium makes a total of 3.769 per cent and sodium 30.637.

The matter, however, is plain that a large proportion of the magnesia compounds is drawn downwards towards the centre of the earth, as in the case of iron and nickel. Whenever limestone is subject to pressure making the exchange of substances easy from the acquired mobility of the molecules, there dolomitisation is pronounced. Spurr, for instance, describing the faults in limestone in the Aspen mountain, Colorado, states that along the fractures the limestone is changed to dolomite, and the farther one passes from them the less magnesia there is in the rock.[1] Prestwich states that in the carboniferous limestones of Kilkenny and Cork the upper surfaces and parts of the rock along the bedding and joint planes are altered to dolomite, whereas the deeper lying portions are pure limestone[2]; the same is a familiar feature in the North of England where the joints in the mountain limestone are bordered with a yellow dolomite or dunstone.[3] The same effect on a larger scale is shown in the Cambro-Silurian limestones of North America. In the Appalachians where the folding has produced intense pressure the whole formation has been changed to dolomite, whereas the same rock in the undisturbed region of the Mississippi valley is unaltered limestone; in the latter case one must suppose that the same amount of magnesium compounds has passed through, but the absence of pressure prevented the chemical interchange between the solution and the rock taking place.[4]

Can we explain these facts on the same principle as that which we adopted in the case of iron, namely, that the great nucleus of magnesium rocks below the crust has exerted

[1] J. E. Spurr, "Geology of the Aspen Mining District, Colorado," *Mon. U.S. Geol. Survey*, vol. xxxi. 1898, p. 212.

[2] J. Prestwich, *Geology*, 1886, vol. i. p. 113.

[3] A. Geikie, *Geology*, 4th ed. 1903, p. 436.

[4] C. R. van Hise, "A Treatise on Metamorphism," *U.S. Geol. Survey, Monographs*, vol. xlviii. 1904, p. 800.

an attraction on the magnesium salts in solution at the surface? The facts point in that direction, but I know of no experimental data to explain the phenomenon. Ordinary ionisation cannot help us in the matter, because the metallic ions are all charged with positive electricity, and hence a negatively charged centrosphere would attract not only magnesium and iron, but calcium, sodium, potassium, and all other metals.

In this connection reference should be made to Vogt's work on the relative distribution of the heavy metals and the concentration of minute traces of these in igneous rocks to form ore-bodies. Vogt found that there was some rule with regard to igneous rocks whereby one class seemed to attract to itself certain elements, whereas another affected others. We can only note the fact at present, but if there is any truth in the argument advanced in the case of iron, then this may eventually afford a clue to explain the occurrence of the other elements. The following is Vogt's list.[1]

Elements preponderating in—

Acid Igneous Rocks	Basic Igneous Rocks
Silicon to a great extent	Silicon to a lesser extent
Potassium and Lithium	
	Barium and Strontium
Beryllium	Magnesium
	Aluminium
	Iron, Manganese, Nickel, Cobalt
Tungsten, Uranium, Molybdenum	Chromium
Tantalum, Niobium	Vanadium
Cerium, Yttrium	
Tin, Zirconium, Thorium	Titanium
	Gold, Platinum, Iridium, Osmium
Boron	Phosphorus
	Sulphur
Fluorine	Chlorine

The above list at any rate shows that mere specific gravity cannot account for the selection of lighter materials in the

[1] J. H. L. Vogt, "Über die relative Verbreitung der Elemente, besonders der Schwermetalle und die Konzentration des ursprunglich fein verteilten Metallgehaltes zu Erzlagerstatten," *Zeitschr. Prak. Geol.* 1898, p. 314.

earth's crust and denser ones in the interior; there is some agency at work, which, in the processes going on in the crust, weeds out elements and sends them downwards to accumulate beneath the crust, others outwards to increase the salt content of the sea, and retains others as essential to the solid crust from which the continents are formed, with their particular composition on account of this process.

CHAPTER IX

HEAT

THE question of heat in the earth's crust is a matter which can only be discussed thoroughly from a physical point of view. It is generally accepted that below a certain depth to which variations of temperatures at the surface can penetrate, there is a steady increase of temperature as we go downwards. In round figures this is estimated at 1° F. for every 60 feet; that is to say, if the variable zone is 100 feet and the surface temperature 60° F., at 700 feet there would be a temperature of 70° F., at 6100 feet 160° F., and at 60,100 feet 1060° F. With this increase boldly established as an average of many different rates, the nebular hypothesists reckon that at so many miles deep in the earth's crust all known substances will be in a state of fusion. If they are not liquid, then the pressure alone keeps them solid; but should a crack penetrate to these depths the pressure is relieved, and up come the molten lavas in volcanic pipes. This theory stands upon such apparently indubitable facts, explains so many phenomena in one swoop, and is so ingrained in the general mind by scores of years of teaching by geologists, that it is exceedingly difficult to induce people even to entertain the idea that in all probability the explanation is a false one from beginning to end, that it is without any real foundation in the facts.

To begin with, the rate of increase of temperature in the earth's crust is so variable at different places that it is impossible to strike an average. In regions like at Anzin near Valenciennes, we find an increase of 1 degree F. for 28.1 feet. At Minas Geraes in Brazil 1 degree F. for 157.2 feet;

slower rates even than these have been recorded, such as from Calumet in Michigan in a depth of 4712 feet, the rate was 1 degree F. for every 223.7 feet, and in South Africa, in the deep levels of the Witwatersrand mines, the rate varies slightly about 1 degree F. for 225 feet. In the British Isles alone the rate varies from 1 degree F. for every 34 feet to 1 degree F. for 130 feet.[1]

This is hardly surprising from what we have said in regard to the work of underground water; the earth's crust, below a very moderate depth, is a veritable chemical laboratory, where reactions are going on at ever-increasing rates as we go downwards, and in enormous volumes. Some of these reactions absorb heat, others give out heat, and both processes will materially affect the temperature of the rock adjacent to where the changes are going on. Pyritic carbonaceous shales at depths to which water containing oxygen can penetrate, actually burn as in a fire, and water issuing from them becomes heated; such rocks, for instance, in the Dorsetshire lias have given rise to boiling springs and steam fumaroles. As we go downwards, the reverse action takes place and oxidised compounds become pyritised with locking up of heat, so that the temperature gradient in a continuous mass of ferruginous carbonaceous shale would show a rapid increase in temperature near the surface and an actual decrease farther down.

Barus has pointed out in a publication of the American Survey that the solvent action of water on silicates, with decrease of volume, results in heat being given off, and he has suggested that from this cause alone the temperature gradient usually recorded is far too high.[2]

The following temperatures are given by Geikie for the Rose Bridge Colliery shaft at Wigan:[3]—

[1] W. J. Sollas, *The Age of the Earth*, 1905, p. 18.

[2] C. Barus, "The Compressibility of Liquids," *Bull. U.S. Geol. Survey*, No. 92, 1892, p. 84.

[3] A. Geikie, *A Text-book of Geology*, 4th ed. 1903, p. 62.

Depths in yards.	Increase in feet.	Increase for 1° F.	Temperature (Fahr.).	Increase.
558			78	
605	141	70.5	80	2°
630	75	25	83	3°
663	99	48.5	85	2°
671	24	24	86	1°
679	24	24	87	1°
734	165	110	88.5	1.5°
745	33	66	89	.5°
761	48	32	90.5	1.5°
775	42	28	91.5	1.5°
783	24	48	92	.5°
800	51	51	93	1°
806	18	36	93.5	.5°
815	27	54	94	.5°

In a single shaft, therefore, the rate varies from 25 feet to 110 feet for every degree Fahrenheit.

Generally it may be said that areas of metamorphic rocks and granite have low gradients, with a tendency to approach the rate of 1° F. for every 200 feet, whereas in more recent beds, where the readjustment of the rock-grains has not reached an equilibrium, the rate approaches 1° F. for every 50 feet.

The conductivity of the rocks above the particular stratum in which a particular increase is measured will also affect the rate, for if it be one with a low co-efficient of conductivity, then the heat developed will be kept in, whereas in the reverse case it will flow outwards. On a large scale this produces very great results, for the escape of boiling water and molten rock in volcanoes carries quickly to the surface an enormous amount of heat that otherwise would have to leak out through the superincumbent strata, and which would be thereby heated; in other words the temperature gradient would be accelerated.

In the St. Gothard tunnel, Stapff[1] observed in the central

[1] This and the following facts are taken from the Presidential address, Section C. *Brit. Assoc. for the Adv. of Sci.* 1908, by Prof. John Joly.

portions temperatures which worked out at a gradient of 46.6 metres for 1° C. with small irregularities which he attributed to cold springs and the decomposition of the rock. At the north end, where the tunnel pierces the granite of the Finsteraarhorn Massif, there is a rise of temperature sufficient to make the gradient 20.9 metres for every 1° C. Stapff explained this last rapid increase by imagining that the granite retained some of the original heat of its molten condition, but Prestwich, on the other hand, preferred to look upon it as the result of mechanical actions which had comparatively recently been in progress, and to which the upheaval of the Alps was due. In the more recently bored Simplon tunnel, Stapff, basing his estimates on the experience obtained in the St. Gothard, predicted a maximum temperature of 47° C. while others predicted much lower ones. The actual temperatures observed, however, rose at the north end to 55° C. and caused immense difficulty in ventilation and working. This unexpected high temperature was believed by Fox to be due to proximity to volcanic rocks, but nothing of the sort has been noticed on the surface. This fact, nevertheless, shows how impossible it is to estimate increase of temperature in the earth's crust; in the Simplon case the excess of heat almost stopped the working, whereas the deep levels of the Witwatersrand, which should be almost unbearably hot if the established temperature gradients existed in nature, are comparatively cool.

Joly, who investigated the Simplon and St. Gothard rocks with a view to ascertaining their radium content, found that the amount of radium contained in the various types encountered corresponded in a remarkable way with the temperature gradients, so that in the high gradient region of St. Gothard the amount was 14.1 billionths of a gramme per gramme of rock, whereas in the low gradient region it fell to 3.3 billionths. In regard to the temperatures of the two tunnels, the following tables show the same correspondence :—

SIMPLON TUNNEL: AMOUNT OF RADIUM PER GRAMME OF ROCK IN BILLIONTHS OF A GRAMME

Jurassic and Triassic altered sediments	6.4
Crystalline schists, partly Jurassic and Triassic, and partly Archæan	7.3
Monte Leone gneiss and primitive gneiss	6.3
Schistose gneiss	6.5
Antigorio gneiss	6.8
Mean for all rocks	7.1

ST. GOTHARD TUNNEL: RADIUM PER GRAMME OF ROCK IN BILLIONTHS OF A GRAMME

Granite of Finsteraarhorn	7.7
Maximum	14.1
Usernmulde	4.9
St. Gothard Massif	3.9
Tessin-mulde	3.4
Mean in central section	3.3

From Joly's figures there can be no doubt left in one's mind that radium has at any rate a very great influence on the temperature observed in rocks, if it is not entirely responsible for all of the heat in the earth's crust. But the work of Strutt, who initiated this kind of research, is still more positive.[1]

The following table is taken from his work on the distribution of radium in the earth's crust and on the earth's internal heat:—

Rock.	Locality.	Radium in billionths of gramme per gramme of rock.
Granite	Rhodesia	9.56
,,	Cape of Good Hope	7.15
,,	Shap Fell, Westmoreland	6.63
,,	Isle of Rum	.676
Olivine basalt	Skye	1.32
Basalt	Victoria Falls	1.26
,,	Ovifak, Greenland	.613
Dolerite	Isle of Canna	1.24
,,	Loch Scaivig	.664
Stony meteorite	Dhurmsala	1.12
Iron meteorite	Three specimens	0
Native iron	Disco, Greenland	.424

[1] R. J. Strutt, "On the Distribution of Radium in the Earth's Crust and on the Earth's Internal Heat," *Proc. Roy. Soc.* Ser. A. vol. lxxvii. 1906, p. 479.

The general sense of the analyses of the thirty-three specimens tested is that the radium content is higher in the siliceous than in the basic rocks, and that meteoric iron is free of radium. Assuming that the rate of increase observed in the crust of the earth is 1° F. for every 42.4 feet, according to Prestwich's mean, then if all this heat were solely produced by radium contained in the earth, the amount would be .175 billionths of a gramme per gramme of earth substance, taking it all through. All igneous rocks, however, contain far more than this; the poorest of all, the Greenland basalt, contains 10 times as much and an average rock from 50 to 60 times as much.

If, then, the earth cannot contain on an average more than .175 billionths of a gram per gram of substance, and that 5 billionths is a representative value for rocks in the crust of the earth, then not more than $\frac{1}{30}$ of the earth's volume can consist of material similar to that encountered on the surface. This would give a depth of the rock-crust of about 45 miles, assuming a total absence of radio-active material within. Suppose, further, that all the heat in the earth's crust is produced by radium, then the temperature at the base of the 45 miles will be 1530° C. Radium has been tested up to 1200° C., at which point no diminution of its properties was observed, so that there is no reason to suppose that the temperature at the base of the rocky crust would interfere with the emanation of heat. If, however, the earth's nucleus is at a temperature of −273° C., the bottom of the crust will be cooled by radiation and heat-absorbing chemical changes.

From Milne's researches on the propagation of earthquakes it is apparent that at a depth of 30 miles there is an abrupt change in the constitution of the earth, and earthquake waves are transmitted below this level at a different rate from that in the crust, showing that the nucleus is more rigid and of a different nature altogether from the materials outside it. Strutt's estimate of the radium of the globe, then, gives us more than we want. It may be taken that the

general average of crustal rocks is higher than the one taken, and that, therefore, 30 miles would be sufficient to explain the amount of leak. I think it is more in accordance with facts to accept Milne's estimate of 30 miles; to take Strutt's average of the radium content and to supplement the sources of heat within the earth's crust by the sun's heat, by chemical changes, by compression, by movement of earth segments, and perhaps by residual heat left by the impact of the original meteoric material.

There are many uncertain factors in the calculation still impossible of estimation. The earth is not a warm body floating in a bath of warm ether, but the outer space is intensely cold. Reckoning the temperature of this at $-273°$ C., the average temperature of the earth's surface would be 283° to 288° C. absolute. The interior of the globe also must be supposed to have cooled down to the temperature of absolute zero; the heat developed by the impact, when the earth was in an earlier stage, would have been radiated out into space, and the compression of the whole would have caused the nucleus to settle down into a state in which no movements could cause increase of temperature. If the axis were altering its position, then the shearing within the mass would certainly cause such friction that a high temperature could be maintained, but there is no reason to assume that this has taken place within the later stages of the earth's development. What little shifting there has been has been accommodated on the outer crust. There is no escape from the conclusion that the crust of the earth maintains its own temperature against an absolute zero of $-273°$ C. without, and an inner nucleus which would be at the same temperature but for what is radiated into it from the crust. If the earth were a small body with a hot jacket, the centre would assume the temperature of the outer covering, *i.e.* 1530° C. according to Strutt; this temperature is a maximum, and must be reduced considerably to account for the absorption of heat by chemical reactions accompanying metamorphism under great pressures.

The radiation of heat from the earth is not, however, unobstructed. The atmosphere contains a certain amount of carbon dioxide and water-vapour; Arrhenius has found that heat rays emitted from a body at 15° C. through carbon dioxide suffer an absorption of 25 per cent in 300 centimetres, and the same amount in 6.8 centimetres of water-vapour measured as water.[1] A total clearing of the atmosphere of carbon dioxide would cause a reduction of the surface temperature of the earth of 14.6° C., and the reduction of the water-vapour, following as a secondary effect, would induce a further fall of 12.5° C., or 27° C. in all.[2] To obtain the temperature of the Eocene period in Europe, reckoned at an excess of 9° C. over the present temperature, the carbon dioxide would have to be increased by 300 per cent; to reduce the present temperature to that of the Ice Age, that is to say, to cause a fall of 4.5° C., the carbon dioxide would have to be reduced by 50 per cent.[3]

Chamberlin estimates the amount of absorption of heat by the earth's atmosphere empirically by comparing the earth with the moon, which has no atmosphere.[4]

Temperature on the Surface of an Atmosphereless Planet

Temperature of the moon's surface at midday	370° C. absolute
Temperature of the moon's surface at midnight	55° C. ,,
Mean temperature of moon's surface	214° C. ,,
Temperature of earth's surface (15° C.)	288° C. ,,
Difference due to blanketing of earth's atmosphere	74° C. ,,
Maximum of other estimates	124° C. ,,

Therefore the efficiency of the atmosphere as a thermal blanket may be estimated as a total of about 100° C.; the mean of these estimates, or, in other words, the earth's surface temperature, would be 100° C. colder were it not for the atmosphere. Van Hise on the other hand estimates that the surface would be colder by 200° C. were it not for the sun's heat, and states that the effect of this heat must be felt down-

[1] S. Arrhenius, *Kosmische Physik*, vol. ii. 1903, p. 503.
[2] H. Rubens and E. Ladenburg, *Verh. d. deutsch. phys. Gesell.* vol. i. 1905, p. 171.
[3] Svante Arrhenius, "Die physikalischen Grundlagen der Kohlensäuretheorie der Klimaveränderungen," *Centralblatt f. Min., Geol. u. Pal.* 1909, No. 16.
[4] T. C. Chamberlin and R. D. Salisbury, *Geology*, vol. ii. 1906, p. 674.

wards for 6000 metres, but he includes in this the effect of the congelation of water on the surface of the earth and all the changes which are brought about by the free circulation of this agent.[1] The absorption of heat from the sun's rays, however, would produce by itself a gradient of the reversed order to that which we actually find in the earth's crust, that is to say, the further from the surface the less would be the heating effect produced, so that as a source of heat in the earth's crust the heat from the sun must be negligible compared with that derived from other sources.

In 1873 Mallet published a paper on the heat developed on the crushing of rock by its own weight, and ascribed the extrusion and intrusion of igneous rock to the melting effected in this way.[2] He was followed by Le Conte and others, but Fisher objected to the theory on the grounds that, though undoubtedly an immense amount of heat was developed, it was produced slowly over the whole mass and could not be localised. To say, for instance, that a cubic mile of rock reduced to powder would in the process give off so many calories sufficient to melt a tenth of the whole, does not mean that that tenth would be fused.[3] Mallet did not recognise the rôle of solvent water in the earth's crust where the minerals give way by solution long before the crushing strength of the rock is reached, and, except in very rare instances, there does not occur in nature that grinding of particles one over the other which Mallet relied upon for the production of his high temperatures. That Mallet pointed out a constant source of heat in the earth's crust is unquestionable, but the matter has been put on a firm basis by Helmholtz's theory of self-compression. Hilgard suggested that if fusion by mechanical means occurs in the earth's crust, then it must be at the junction of segments of

[1] C. R. van Hise, "A Treatise on Metamorphism," *Monograph U.S. Geol. Survey*, vol. xlvii. 1904, p. 51.

[2] R. Mallet, "Volcanic Energy; an Attempt to Develop its True and Cosmical Relations," *Phil. Trans. Roy. Soc.* vol. clxiii. 1873, p. 147.

[3] O. Fisher, *Quart. Journ. Geol. Soc.* vol. xxxi. p. 469; *Phil. Mag.* October 1875.

it which rub together in faulting.[1] The development of Helmholtz's theory by Arrhenius, whereby the centre of the earth is conceived to be so highly heated as to be in the condition of a gas kept solid by pressure, is one which is founded on sound mathematical reasoning, but there are so many unknown and unknowable elements in the hypothesis that though it may be a true explanation of the facts, it cannot be admitted here under the conditions of argument which we have set before us in this book.[2]

The production of heat by the movement of earth-segments over and against each other is a constant source of heat which is more easily comprehensible to geologists. The exposition of this has been rendered the more easy by the magnificent memoir on the North-Western Highlands of Scotland, recently published by the Scottish Geological Survey.[3] In this district the Archæan schists have been subjected to a thrust which has broken the rocks across and thrust the fragments one over the other like when one pushes with one's fingers a film of paraffin wax hardened on the polished wood of a table. Then an enormous final thrust has occurred which has transported millions of tons of rock horizontally over many miles of country. Mellard Reade has objected that the dynamical force requisite to accomplish such movements is almost outside the bounds of possibility by reason of its vastness, yet field evidence of the closest and most exacting description has indubitably established the existence of these transported blocks.

In the extreme north of Sutherland in Scotland the various rock-groups included in the term Eastern schists, and situated above the Moine thrust-plane, can be shown to have been thrust westwards for a distance of 10 miles from

[1] E. W. Hilgard, *Am. Journ. of Sci.* 3rd ser. vol. vii. 1874, p. 535; *Phil. Mag.* 1874, p. 45.

[2] Sv. Arrhenius, "Zur Physik des Vulcanismus," *Geologiska Foreningens i Stockholm Forhandlingar*, vol. xxii. 1900, p. 395; *Geol. Mag.* vol. iv. Dec. 5, 1907, p. 173.

[3] A. Geikie, J. J. H. Teall, B. N. Peach, J. Horne, W. Gunn, C. T. Clough, L. W. Hinxman, "The Geological Structure of the North-West Highlands," *Mem. Geol. Survey of Great Britain*, Glasgow, 1907.

the hill-slopes on the east side of Loch Eireboll to the centre of the Durness basin and the promontory of Fair-aird Head. Again, near the county boundary between Sutherland and Ross, the great overlap of the Eastern schists can be traced continuously for a distance of 6 miles across the broad belt of folded and thrusted materials in the Assynt Mountains. It seems to be a general rule that the gneiss in the disturbed area has been thrust several miles southwards from its original position. The most remarkable example of this tectonic feature is to be found in the Glencoul district, where the thrust gneiss, with broad veins of red pegmatite and basic dykes, has been shifted southwards for a distance of 6 miles from Ben Stack to Glencoul. In the case of the piled-up segments of rock in what is called by the Scottish Survey officers the imbricate structure, it is obvious that there has been great lateral displacement of zones, though it is difficult, if not impossible, to form any reliable estimate of its extent.

Displacements of this nature have been mapped and recorded by Briart, Cornet, and Gosselet in the exhaustive survey of the Franco-Belgian coal-field, and the beautiful sections of the underground structure of this area have long been models for illustrating the nature of thrust-planes.

But it is in the Alps especially that this feature has been studied, not, however, accompanied with that attention to minute details which has characterised the Scottish, French, and Belgian surveys, yet the facts in broad outline have been firmly established. One can refer to the works of Heim, Bertrand, Suess, Lugeon, Kilian, Haug, Termier and many others for evidence of this great overthrusting or *chevauchement* as the French call it. In this area folds have been driven outwards along planes which approach the horizontal, and the crests ride over the underlying younger strata for 10 miles and more; the roots, meanwhile, being in continuity with the central areas of the mountain chain. Eventually, either by an excess of the crushing, whereby the top of the recumbent fold is left lying isolated on the surrounding beds, or through the subsequent agency of weathering and erosion,

these rocks, born from the central axis of the mountain, are found perched upon the tops of hills in the plains bordering the folded mountains. The most recent beds thus capped with ancient plicated strata are the Tertiary Flysch, which gives us the age of the folding.

There is no folded range of mountains in the world which does not show these thrust-planes, and in South Africa I have observed them in the comparatively slightly folded coastal ranges and in the older intensely folded ranges of the Transvaal, where the thrust-planes are often confounded with planes of unconformity. Where a thrust-plane occurs the friction to be overcome in the process is enormous, and the heating effect, though admittedly not sufficient to melt up the infusible silicates of the rocks, nor developed in a limited time, nevertheless has added to the internal heat of the earth's crust.

Not only in these larger blocks has this movement taken place, but as in the Moine gneisses of the central and north-western Highlands of Scotland, the shearing may take place along innumerable small folds. Barrow calls this structure the concertina structure,[1] for the beds have been crinkled up in the manner of the bellows of a concertina when shut up, and the folds pass indiscriminately through granite, quartzite, limestone, and basic igneous rocks. In these cases the heating effect is not confined to one plane, but is distributed evenly throughout the mass of rock concertinaed.

Wherever pressure comes upon a rock which yields, the mass does not give like a liquid substance, but the substance flows outwards in innumerable laminæ, each one of which may travel in different directions or at different rates to the one on either side. Sorby, who first established this, illustrated his meaning by means of pastry rolled on a board, the board and the rolling-pin representing the pressure between which the pastry is nipped. The effect of rolling is to flatten out the thick cake of dough, and in doing so the substance is separated into thin layers which, by reason of their flowing at different

[1] G. Barrow, "Moine Gneisses of the East Central Highlands," *Quart. Journ. Geol. Soc.* vol. lx. 1904, p. 443.

rates over one another, drag the starch grains into parallel position; when the gas rises in the paste on cooking, the separate layers are divided by air-spaces and become plainly visible.

The same happens in a mud which is compressed either by simple weight of the superincumbent rocks, or when caught in the nip of earth contractions. The layers of the mud become thinner, flow laterally, and in doing so their surfaces rub one against the other and produce frictional heat according to the compactness and hardness of the material. Pebbles imbedded in the mud may be split by this movement and divided into innumerable little parallel planes; and not only so, but these slips, cut as if artificially like a potato might be sliced for salad, are shifted to one side or another according to the direction in which the layer of mud in which it happens to lie moves. The feature is familiar to South African geologists in the Dwyka conglomerate, and I have published photographs of this feature taken from examples from Prieska.[1]

A further peculiar effect, first observed on Table Mountain at Cape Town, is the erosion of such pebbles when embedded in a sandy matrix. In this particular case pebbles of quartz lie in layers in a thin bed; the rock has been compacted and squeezed together by the weight of the overlying rock, and as a result the sandstone has been made to flow over and under the thin layer in which the pebbles lie; as a consequence those pebbles which project above the now reduced thickness of the thin layer have their faces ground down, some on one side and others on both sides in parallel planes. I am indebted to Dr. R. Broom of Stellenbosch for drawing my attention to this fact, which, as far as I know, has not been noticed elsewhere.

All these movements produce general heating of the earth's crust, and explain local increments of the temperature gradient. The movements in faults result in local

[1] E. H. L. Schwarz, "An Unrecognised Agent in the Deformation of Rocks," *Trans. S. Africa Phil. Soc.* vol. xiv. 1903, pl. v. fig. 2.

FIG. 7. CONCERTINA FOLDS, MEIRING'S POORT, OUDTSHOORN, CAPE COLONY.
TABLE MOUNTAIN SANDSTONE

FIG. 8. CLEAVED BOULDER, DWYKA CONGLOMERATE, PRIESKA

To face page 134

heating, which in certain favourable circumstances give rise to molten rock and the production of volcanoes.

The association of volcanoes with fissures is perfectly well recognised; the most notable examples are the fissures in Iceland along which innumerable little volcanic cones are situated. Then the great line of the Andes is another instance, though in this case the linear arrangement is made up of a vast number of groups and divergent lines of volcanoes, which obscure the plan of the whole if any one small area is exclusively studied. I shall return to this point later on, but the fact is unquestioned that, if two great earth segments grind and crush against each other, heat must be developed on a large scale, and that if there be fluxes to lower the melting points of the rock-silicates, there the heat may be sufficient to produce molten rock and volcanoes.

CHAPTER X

EARTH FOLDS

In the Alps continuous deposition in an ocean basin preceded the earth movements which resulted in the upheaval of the range. The surrounding continental land was weathered and eroded, and rivers poured sediment into the submerged area, the floor of which sank to accommodate the increasing load. A fair estimate of the thickness of sediment deposited would be 10 miles. Mellard Reade, in estimating quantitatively the effect of this sinking of the rocks in the earth's crust, assumes that at 35 miles there was a temperature of 3000° F.; in consequence of the sinking of the crust under the load of sediment in the Alpine basin, rocks once at a depth of 25 miles in the earth's crust were carried down to a depth of 35 miles, and their temperature would be thereby raised by 857° F., taking the mean rate of increase of temperature in the earth's crust at 1° F. for every 60 feet, and a mean surface temperature of 50° F. The rocks above the original 25-miles level up to the surface, now between depths of 35 miles and 10 miles, would have a mean increase of 428.5° F. The expansion of rocks may be estimated for all kinds at a mean of 2.77 feet linear for every mile raised 100° F.[1] If this rate holds good at high temperatures, then every cubic mile raised 428.5° F. will be elongated by 11.869 feet on every side of the cube, or $\frac{1}{148}$ times its volume; in other words, 148 cubic miles would become 149 cubic miles. If the Alpine depression extended over a distance of 500 miles by 500 miles, then the portion of the crust 25 miles thick would be increased in volume to the extent of 42,230 cubic miles.

[1] T. Mellard Reade, *The Origin of Mountain Ranges*, 1886, p. 115.

As a matter of fact Heim estimates the expansion across the Alps at 74 miles linear; if the expansion in the length were the same, a vertical uplift of 8 miles would correspond to Mellard Reade's estimate, which is quite a possible uplift, seeing that while it was in progress the agents of denudation were continuously working to carry away the upper portion; and not only must there have been an upward movement vertically, but a downward one must also have occurred.

This is a concrete case which is illustrative rather than explanatory. Rocks do not remain solid in this way, but owing to the easy solubility of their constituent minerals in water at high temperatures and pressures, they yield, flow, and recrystallise in such a way that direct earth-thrust cannot be transmitted. With a knowledge of this fact, which is again and again emphasised in every modern book which treats of metamorphism or metamorphic rocks, what would the consequence be of a stratum 25 miles thick subjected to a load of rock 10 miles thick in the middle? The same thing would happen if a 14-lb. weight were placed on the top of a pailful of putty: the material would squeeze out round the edges. This actually happens in the great geo-synclinals that defines, for instance, the borders of the Pacific, where the edges are riddled with volcanic vents vomiting the rock squeezed out from under the foundered segments of the crust. In the more limited areas of mountain-building, however, the rocks are not squeezed out but are thrown into folds.

With tangential pressure produced by earth contraction, or inversely, by expansion of an earth segment between immovable blocks, rocks would behave in the same way. A homogeneous bed of sandstone at 5 miles' depth within the earth's crust, if caught in the nip of such a pressure, would have its constituent sand-grains transformed into discs flattened normal to the direction of pressure. Such an extreme case does not happen, because the weight of the rocks above would prevent the vertical flow which such a

horizontal contraction would necessitate, but so much accommodation would be provided for in the bed of sandstone that a force striving to be transmitted through it would soon be lost. Supposing the rocks immediately above and below the sandstone were perfectly rigid and water-tight, then the force to be transmitted through the sandstone would act as if it were applied to a liquid. In nature, however, rocks are not water-tight, and they are so far from being rigid that apart from their property of being dissolved and redeposited, they are always ready to give way to any pressure owing to the constant tremors which agitate the earth's crust. If, then, we recognise that silica and silicates become soluble under pressure, force cannot be transmitted through a stratum of rock in the zone in which solution and redeposition can go on. Above this zone the rocks are fractured. Cavities can and do exist, and water no longer permeates only the rock substance but circulates in the fissures as well. Such material is not a fit one to transmit great and prolonged pressures. If we look at the folds in any considerable mountain range, we shall find that if we are to imagine that the top fractured segment of rock is to account for the transmission of the lateral pressure which buckled up the mountains, it must have been thrust several miles' distance over the underlying strata. The actual mileage does not concern us here, but the fact remains that rocks fissured and structurally weak as we find them, must, on such a supposition, have been bodily transported, despite their weight, and have carried with them a battering power sufficient to crumple up rocks as resistant, at any rate, as themselves. It is evident, therefore, that neither in the zone of fracture, nor in the zone of flow, can lateral thrust be transmitted for any distance in the earth's crust.

In casting about for an adequate cause for the folding of mountain chains which had not the disadvantages above referred to, and at the same time to take into account all the forces at work on the earth's surface such as we know them, it is evident that in all accepted theories the small

movements in the earth have been left out of account. These small quakes are, however, always in evidence. A mirror hung by two strings of unequal length from the ends of the two unequal arms of an upright beam exaggerates any tilting that occurs on the surface of the earth, and a beam of light reflected from it shows that it is in constant motion. A man walks along the street and causes the earth to vibrate; seventy-four men will tilt a great building; a luggage-train

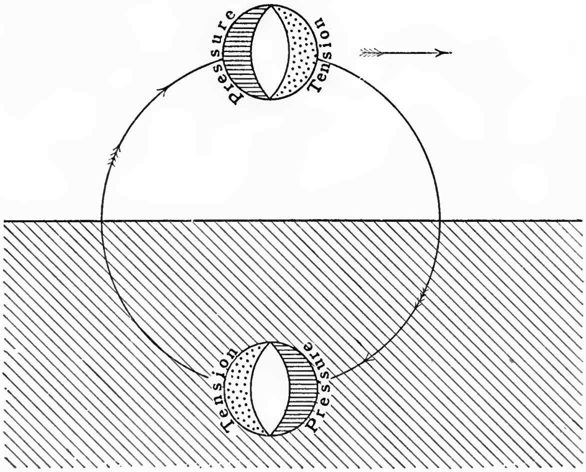

FIG. 9.

The stresses on a sand-grain in an earthquake wave, the shaded portion being under greater, the dotted portion under less pressure. The large circle shows the path of the particle in a normal wave; the shaded portion represents the medium which, being denser, damps out the lower portion of the wave. The sand-grain, therefore, will be under stresses represented in the upper half; its material will be dissolved uniformly from the back, and will be added to in front, so that the sand-grain as a whole will move in the direction of the straight arrow.

will shake a mountain. These vibrations, however, are directed to no particular end; the effect of one set will be counteracted by the next and the sum total of the displacements in a year will be nil. If, now, these vibrations are constantly proceeding in one direction then the effect will be cumulative. For instance, every day the rivers along a coast discharge so many tons of sediment on the sea-floor adjacent, the floor sinks, rock is carried lower in the earth's

crust and heated; vibrations due to the readjustment will constantly be propagated and in a constant direction. Let us follow the effect on a grain of sand in a sandstone buried moderately deep in the earth's crust.

The grain lies surrounded with water which is ready to dissolve a portion of its substance directly some differential stress comes upon it. A vibration comes along, tends to move it, but the vibration, if free, will leave the grain at the end in the same condition as in the beginning. But suppose that the return vibration is damped out by some obstruction such as a rigid boss of granite, then there will be a tendency for the grain to move forwards, pressure being applied behind and a lesser pressure in front. But substances under pressure have their substances dissolved by water, and those under less pressure will have the same substance deposited; hence the grain will lose substance in the direction of the origin of the wave, and have substances added to it on the other side. As a result the grain will move forwards. For any one wave the substance affected will be very small indeed, but the aggregate in centuries would allow the grain to be wholly transposed and moved continuously forwards. Not only the individual grains but the whole rock stratum would be by these means made to travel forwards in the direction away from the origin of the vibrations, and whole mountain masses will become piled up in consequence.[1]

This action is beautifully illustrated in miniature in the sheet of lead at the bottom of the kitchen sink which Mellard Reade has described.[2] Lead is too pliant to transmit pressure, yet at one end of the sink, in response to a disturbing force represented by the alternate heating and cooling effect from the water let in by the hot and cold water taps, there arises a well defined anticlinal ridge at the other end of the sink. The explanation of this lies in the expansion and contraction of the metal at the tap end of the sink, which set up compressional waves. These passed through the main body of

[1] E. H. L. Schwarz, "Rock Folds," *Science Progress*, vol. i. 1907, p. 569.
[2] T. Mellard Reade, *The Evolution of Earth Structure*, 1903, p. 139.

the sheet of lead, producing very little effect until they became retarded by the fixture of the sheet to the wooden sides of the sink. The sum of these constantly repeated waves produced a permanent distortion; the return wave, which would have shifted the individual particles back to their original positions, being damped out.

In the south-western portion of South Africa we find a very close imitation of Mellard Reade's sink, or rather one of

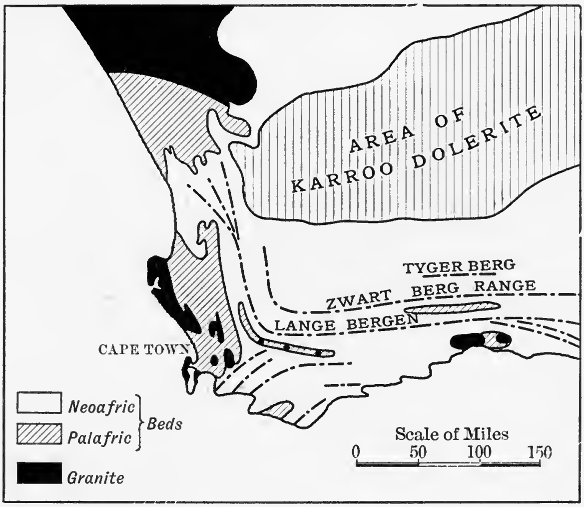

FIG. 10.

Map of the south-western corner of Cape Colony, showing the directions of the axes of the mountains, the area of the intruded dolerite dykes and sheets, and the granite and Pal-Afric beds on the coast.

the far corners of it. The newer Cape rocks, the Neo-Afric beds, rest on an older series, the Pal-Afric, in such a way that these latter form an upturned edge set nearly at right angles; the Pal-Afric beds are further stayed by heavy intrusions of granite, which accentuate the angular outcrop. The granite and Pal-Afric beds would represent in Mellard Reade's sink the sides, and would also represent the wooden bottom, for they pass beneath the Neo-Afric series in the centre of the Karroo. The disturbing cause, the hot and cold water of the

sink, is represented by a very heavy intrusion of dolerite in the form of sheets in the central portion of the Neo-Afric region. The disturbance is represented by several ranges of closely-folded mountains, which follow the lines of the granite external to them.

It was for a long while a matter of dispute as to whether the force which buckled up these mountains came from the interior or from the side of the ocean. It has, however, recently been found that on the south-eastern coast, a little to the east of George where the granite ends, there is a significant change in the character of the folds. Where the granite bars the way to the sea, the folds in the mountains internal to it are closely huddled together and follow the trend of the granite outcrop in their east and west strike. Where the granite ends, the folds widen out and curve seawards so markedly that the feature can be noticed even in small-scale topographical maps, with shaded mountain ranges.

This feature in the south coast of Africa might be explained by the granite having been thrust northwards as an immense ram into the yielding strata; but then the same features exist on the west coast, where the granite runs north and south and the strike of the mountains follows suit till the granite ends, when the folds fan out seawards. It is inconceivable that two extended masses of granite should have travelled the one northwards the other eastwards, and have clamped the rock formations between them. It has taken ten years' continuous field-work to prove this point, but it has been accomplished.

As regards the disturbing cause, the dolerite intrusions, it is hard to convey any sense of the magnitude of these. They cover an area of over 70,000 square miles, and the separate sheets are ranged one above another, sometimes spreading out into laccolites, when the whole country for miles is one black mass of dolerite. More extensively they occur as sheets, one of which in the western Karroo has a superficial area of 3000 square miles; but the buried portion of this is probably four times as much again. The sheets

also may be from 200 to 300 feet thick. With so great an amount of molten material thrust into the Karroo rocks some effect must have been produced by the expansion, letting alone the space occupied by the intrusions themselves. Whether they melted out a passage for themselves or simply occupied pre-existing fissures is a problem with which we are not immediately concerned.

The effect of the disturbance caused by the dolerite intrusions is shown in the folded coast ranges. Between the folded mountains and the escarpment where the dolerite begins, there is a denuded area about 30 miles across. In it there are occasional flexures, but on the whole the shales and sandstones of the Karroo beds of which it is made lie practically horizontally, and they are traversed by quartz veins. This last feature is an important one, for it shows that while the disturbance of the dolerite intrusion was being transmitted to the outer edge of the Neo-Afric region, the intervening track was so far from being in compression as to be traversed by open fissures, which subsequently became filled in with vein quartz. Curiously enough this last feature is faithfully reproduced in Mellard Reade's sink, for in the centre of the sheet of lead, which in this case unquestionably transmitted the thrust which buckled up the lead at the far end, there are a number of transverse fissures, in this case gaping and empty.

I have taken my example from South Africa, as it is the one which I know intimately, and the problem is such that it cannot be adequately discussed from maps and sections alone; but there are, no doubt, similar instances to be found in any part of the world.

Such, then, is the mechanism of mountain-building which our method of letting facts explain themselves, so long as we take all the facts, leads us to conceive.

Is, however, the old theory that the beds were buckled up by tangential pressure inadmissible? Could they not have been rendered plastic by solution and then nipped in the jaws of closing segments of the earth? From the conditions that

prevail, making it impossible for earth-thrust to be transmitted directly through rocks, we have answered this question in the negative ; shearing and cleavage can be produced as a result, but not folding. An examination of a rock-fold in the field will, from the *a posteriori* point of view, show that the process has been accomplished while the strata were solid.

This fact is a familiar one where beds are folded into sharp synclines and anticlines ; the strata fail to adhere in the apex of the fold, and gaping hollows are produced, which in deep-seated rocks are filled in with vein quartz. This feature can be reproduced by bending, say, a number of sheets of zinc lying one upon the other ; but if the same thing is attempted with a number of layers of putty with a weight resting on the top, the folds will be solid. The latter would be the condition of rocks if they were rendered sufficiently plastic, by being deeply buried, for earth-thrust to be able to crumple them. Not only do the individual beds fail to adhere in the axes of the fold, but sometimes there is seen a reverse fold in the apex like an M within an inverted V, ; that is to say, while the rock was apparently soft enough to bend, it yet had sufficient tensile strength to crumple backwards the rock inside the fold. If we explain such a phenomenon by direct earth-thrust, we are landed into serious difficulties ; but if we conceive the pressure to have been transmitted by waves gradually moving the rock-substance in accord with the line of least resistance, then the features we see would build themselves up without any trouble.

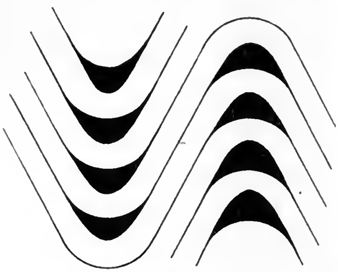

FIG. 11.

Beds of sandstone folded with the thickness of the strata in the apices of the bends equal to that in the limbs, showing the interspaces.

Generally speaking, rocks will move under the influence of mountain-building forces at a rate which varies inversely as the amount of pore-space in the rock. That is to say, a rock with 1 per cent pore-space will move half as quickly as

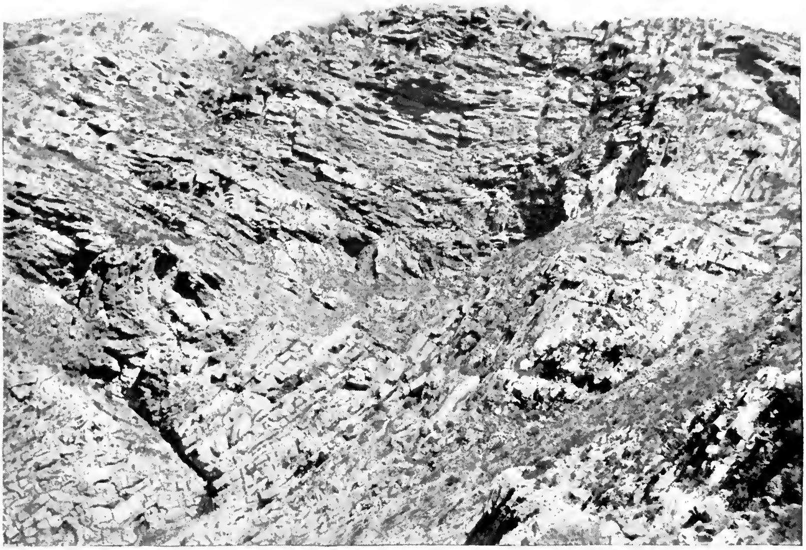

FIG. 12. TABLE MOUNTAIN SANDSTONE, MEIRING'S POORT, OUDTSHOORN; BEDS CRUSHED BACK IN AXIS OF FOLD

FIG. 14. TYGERBERG, PRINCE ALBERT, CAPE COLONY

The mountain is a narrow anticline of thin-bedded quartzite thrust through compact glacial till (Dwyka Conglomerate). The latter is only gently folded and the quartzite has come up in a gap in the axis of the fold.

one with 2 per cent. Other factors come in, such as the solubility of the constituent particles; for instance, a limestone will move faster than a quartzite with an equal pore-space. Clay-rock will move very much slower than a quartzite.

In illustration of these points I have a mass of material, but I will take two instances only. In the first place, if the rocks are similar in composition, then if one bed is more compact than the other, it ought to resist movement more than the others. Such is found to be the fact. The fold illustrated occurs in the Table Mountain sandstone of the

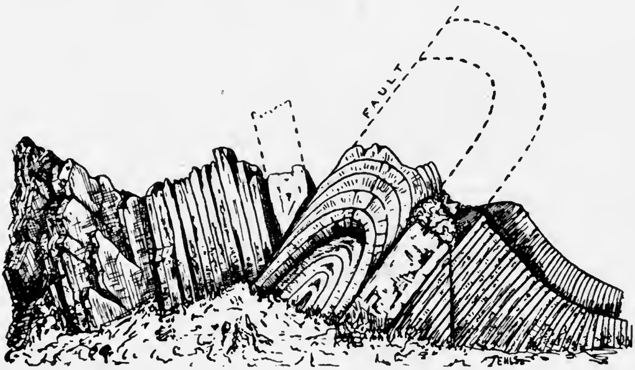

FIG. 13.

Compressed fold in the Zwartberg, Angelier's Bosch, near Prince Albert, Cape Colony.

Zwartberg Mountains, east of Prince Albert in Cape Colony. The rock is usually massively bedded, but towards the top it becomes thin-bedded with an occasional massive bed interposed. The texture of the rock in the thin- and in the thick-bedded strata is identical, but where there are several beds in 10 feet there must be a corresponding number of sheet openings for the circulation of water between the separate layers. Where there is only one bed in 10 feet there can only be the capillary spaces within the rock itself. When the two diversely bedded rocks are folded the thin-bedded rocks move at a very much greater rate than the thick beds, and the features shown in the illustration are produced.

In the case of clay-rock and sandstone, I am unable, unfortunately, to obtain estimates of the pore-space in slates and clay-rocks; the material is not used for building, except for roofing, and there are no data that I can find as to the absorption of water. Clay particles become very closely packed by pressure, and the pore-space in slates and phyllites is uniformly small, whereas in sandstones the pore-space varies according to Buckley's tables from 4.8 to 28 per cent.[1] What actually happens, however, is that if a rock couple consisting of clay-rock and sandstone is caught in compressive earth movement, the sandstone moves at a considerably greater rate than the clay-rock. In the example that I take the clay-rock is the hardened glacial boulder-clay, the Dwyka conglomerate of the south of Cape Colony. It is underlain by compact saccaroidal quartzites, usually thinly bedded, the Witteberg quartzite. In the Tygerberg the two beds have been caught in an anticlinal movement, and the Dwyka conglomerate has been moderately folded but has cracked along the axis. Through this crack the underlying quartzite has come squeezing as if it had been putty pressed between one's hands. Here, again, on the theory of direct pressure, the whole of the rocks would be under equal strain, and such marked differential movements could not take place; but a transmission of the pressure by means of waves would allow this difference, for every little lift would be accommodated twice or three times as fast in the more soluble rock, or the one with more solvent water, than in the less favourably conditioned one.

[1] E. R. Buckley, "Building and Ornamental Stones of Wisconsin," *Wisconsin Geol. and Nat. Hist. Survey*, Bull. No. iv., 1898.

CHAPTER XI

THE EARTH'S SURFACE

THE shape of the earth is not yet known. The great arcs of meridian that have been measured on the earth's surface tell us a good deal, but the measurements from continent to continent across the oceans, from which we could learn so much more, have not been made. Even the measurement of continuous land masses is not complete, and there are still gaps to be filled in in the great arc which is being measured from the Cape of Good Hope to the North Sea, which, however, thanks to Sir David Gill, will soon be filled in. In the absence of accurate measurement we fall back on guesses, and there are two schools of geognostics, each of whom hold diametrically opposite views. The one school maintains that the earth is sensibly spherical, and the other that the earth is like a collapsed tennis ball with four indentations or hollows, filled respectively by the Atlantic, Pacific, Indian, and Arctic oceans, and six ridges forming the outstanding continents. We shall call these the spheroidal and tetrahedral theories.

We are not concerned here with the mathematical side of the question, but we must inquire which of the two conceptions fits in best with what we know of the earth's surface. In the first case we have a spherical globe with continents projecting above the ocean, therefore the attraction of the continents will cause the water to heap up along the shores in such a way that in sailing from America to Europe one would first go downhill till the middle of the journey was reached, and then uphill to the end. This would necessarily be so supposing the crust beneath the ocean to be of equal density and consequently of equal attracting power to the rocks of the

continent ; if the sub-oceanic rocks are more dense than the continental rocks, then the excess of attraction exerted by these would keep the ocean to the spherical contour.

The upholders of the tetrahedral theory, on the other hand, do not need to worry about the density of the sub-oceanic rocks ; the ocean lies in hollows ready made for it, and if the ridges attract some of the water it will not affect the question. It is not to be understood that the tetrahedral theory implies that the earth has assumed the shape from the

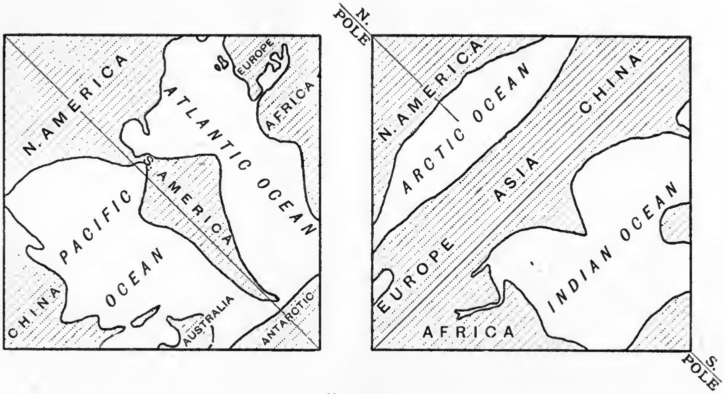

FIG. 15.

The earth in tetrahedral projection, showing how the continents fall upon the ridges of the tetrahedron, and the ocean basins occupy the flat sides. The coincidences have been exaggerated to simplify the conception.

action of molecular forces such as determine the shape of crystals of the mineral tetrahedrite for instance ; we have already had occasion to point out that the laws that regulate very small masses do not apply to larger ones. The tetrahedral conception of the earth's figure is deduced from the shape that a sphere should assume when the nucleus shrinks away from the outer shell. We have rejected the idea of a shrinking globe, and therefore the cause for the earth's surface showing tetrahedralism is likewise thrown out. From other considerations also it is apparent that the theory cannot stand. The rotation of the earth with the nucleus plastic under prolonged strain would have obliterated such features in the long period

of the earth's geological history. Then, again, the earth's surface is not a fixture, it is always in motion; continents have disappeared and have been covered with oceanic deposits, to again emerge from the sea, and so on many times for each land area now exposed. None have escaped these movements. As for the ocean, we know that in Cambrian times the sediments on the west of Great Britain are shore deposits, whereas when we go eastwards they become deep-water ones, pointing to a land mass where the waters of the Atlantic now lie. We shall bring together many other facts bearing on this question in this chapter, but the point to be noticed here is that, had the tetrahedral form been the original one, earth movements from within the crust would have obliterated them. The depressions produced by the initial collapse of the crust might travel round the globe by secular creep, but there are no means of reconstructing the tetrahedral shape across the direction of revolution, if it had once been obliterated.

We come back then to the spheroidal earth, and we have to inquire whether the rocks of the sub-oceanic crust are different from those of which continents are made, or not. Should they be different, then it follows that the ocean basins must be part of the original plan of the earth's surface features, and have remained more or less in the same position that we find them in to-day throughout geological time; that is the theory of the permanence of ocean basins as defined by Dana and Wallace. It follows, also, that the greater density of the sub-oceanic crust will keep the ocean surface spherical as against the pull of the continents that rise from it; the mean density of continental rocks is 2.68, and to counteract the attraction of the continents the specific gravity of the rocks of the floor of the ocean would have to be 2.96.

If the force of gravity is measured on an oceanic island by means of a pendulum, we can tell whether there is an increase or defect in the number of vibrations.

Every vibration in excess of the number which there ought to be during the twenty-four hours, taking the figure of the earth as defined by one of the expressions which regard it as

sensibly spherical, that is either Clarke's or Bessel's, will be equivalent to an approach towards the centre of the earth of 122 metres, and every vibration in defect an elevation of 122 metres above the normal.

The following is a list given by Fisher :—[1]

Station.	Latitude.	Observed variation in excess of normal.
Spitzbergen	80 N.	3.09
Portobello	10 N.	3.85
Galapagos Is.	6 S.	2.43
S. Thomas	0	6.86
P. Gausea Lout	0	4.53
Fernando de Noronha	4 S.	8.22
Ascension	8 S.	6.15
St. Helena	26 S.	9.32
Staten Island	56 S.	2.90
S. Shetland	63 S.	3.90
Miniccy	8 N.	3.49
Mowi	21 N.	4.80
Île de France	20 S.	7.16
Île Bonin	27 N.	11.79
Guam	13 N.	4.88
Occalon	5 N.	9.93
Mean		5.83
Falkland Islands	52 S.	3.85 in defect

Multiply these figures by 122 and one obtains the number of metres the islands are nearer the earth's centre than they would be were they projecting from a spherical ocean surface; thus at the Island of Bonin the sea would rise 1438.38 metres but for the attraction of the continents on the ocean, taking the sea-floor to be of equal composition to that of the continents. The Falkland Islands show a defect, therefore they stand above the normal level by 469.7 metres, and these islands are elevations rising from a continental shelf which is so well defined that the Argentine Republic at one time claimed that they belonged to that country on that ground. All continents show this defect, and Listing has given the following figures of the amounts by which the places mentioned stand above the normal owing to the continental pull on the ocean waters; London, 118 metres; Paris, 263 metres; Berlin,

[1] Osmond Fisher, *Physics of the Earth's Crust*, 2nd ed. 1889, p. 252.

37.7 metres; and Königsberg, 92.6 metres.[1] Suess[2] points out that the relief shown by the continents is very much lessened by this attraction. The upholders of the theory of the permanence of ocean basins deny that this excess or defect of gravity is caused by approach or the reverse to the earth's centre, but can be explained by the density of the rock underlying the recording station; the continents being composed of light material attract the pendulum less than the ocean floor, which is composed of basalt and such-like heavy rocks.

Faye[3] has pointed out that, supposing the ocean surface conforms to the spherical contour, then at a given point in it, if pendulum observations could be taken on board ship, they would be normal. Place, however, under the ship a cone of rock of the density 2.5 (less than that of normal siliceous rocks) measuring 4500 metres (2460 fathoms) in height, with a diameter at base from twice to four times the height, then the number of vibrations at this point would be increased from 3 to 6 more in the twenty-four hours, so that there is no need to ascribe the excess of vibrations at island stations to approach to the earth's centre, or to excess of density in the sub-oceanic crust. Drygalski has likewise pointed out that there are so many considerations to be taken into account that Listing's figures are probably exaggerated.[4]

To understand the effect of this pull, however, one can work out the consequence of the upheaval of the Alps above the sea-level in Tertiary times.

An enormous additional attraction would be afforded by this mass of outstanding material, and the sea would be drawn over the low-lying country to the north; consequently there should be remnants of such a sea in the form of shallow water deposits all over Europe belonging to the late Tertiary epoch, and such is precisely what we do find. Then, when the

[1] E. Listing, "Neue geometrische und dynamische Constanten des Erdkörpers," *Nachr. d. k. Gesell. d. Wiss. zu Göttingen*, 1877, p. 749.

[2] E. Suess, *The Face of the Earth*, Eng. trans. vol. i., 1904, p. 2.

[3] Faye, *Comptes rendus*, 22nd March 1886.

[4] E. v. Drygalski, "Die Geoiddeformation der Eiszeit," *Zeitschr. Ges. f. Erdkunde*, 1887.

destructive work of frost, wind, rain, and so on began their attack on the upheaved mass, cutting it into peak and valley, and removing the debris to the ocean by glaciers and rivers, the attractive force would be lessened, the sea would retire, and the land once more would be uncovered. The physicists are, however, so divided as to the true interpretation of their gravity determinations, that it is simpler to explain the European late Tertiary beds by the ordinary processes of elevation and subsidence of land masses. What we have endeavoured to obtain from this inquiry is some clue to the constitution of the sub-oceanic crust, and the physicists failing us, we must fall back upon the usual methods of geological observation.

We look to oceanic islands to afford us some evidence as to the nature of the sea-bottom. There are two types of oceanic islands; at least two are usually recognised. There are those like New Zealand, New Caledonia, New Hebrides, New Guinea, and so on in the Pacific; Rockall Island, Cuba, Haiti, Puerto Rico, Jamaica, Trinidad, Falkland Islands, South Georgia, and the Sandwich Islands in the Atlantic; the Seychelles and Comoro Islands in the Indian Ocean, which are composed of granite, gneiss, quartzites, slates, and massive limestones, and, in fact, all the rocks which we find on continents. The other kind of oceanic island is the volcanic one, rising as a volcanic peak from the abyss of the ocean. These latter are mostly composed of basic igneous rock of a specific gravity bordering on 3, as against the average specific gravity of 2.6 of continental types of rock. It was thought that these volcanoes threw up their piled lavas from the ocean bed, and that these were samples, so to speak, of the sub-oceanic crust; hence it was concluded that the sub-oceanic crust was of an average density of about 3. Let us now see how erroneous such a conclusion is.

Geologists are apt to read the geology of the whole world in the light of the experience gained in their one corner of it. In the matter of volcanoes, in Europe, where the study of them began, the internal fires belch out flames and molten

rock from chimneys already prepared for them; hence in descriptions of volcanoes it is the adult stage which authors emphasise.

Branco, in Swabia, however, and the South African geologists, have been at work in an area where, in many cases, the initial drilling of the volcanic vent has been all that has happened, and the outbursts of ashes and, later on, of lava have not taken place. Hence to such geologists the first stage is of almost more importance than the later stage. Branco, in his magnificent work on Swabia, calls volcanoes in this stage embryonic volcanoes. What happens generally in the first stage of a volcano is that gases ascend up fissures in the earth's crust with explosive violence, and in so doing shatter and tear from the sides of the vents the rocks on either side, and cast these up on the surface as masses of agglomerate. Later on, when the lava column rises, the head is blown off by the escape of occluded water-vapour, and with the ash so formed there are frequently ejected fragments from the sides of the chimney. Thus in many of these embryonic volcanoes one can go to the necks filled in with agglomerate, and by sorting out the different varieties of rock in them, one can obtain fragments of the underlying strata. The chimney is, in fact, nothing more nor less than a gigantic bore-hole; the core lies ready for inspection, and will tell us the secret of the underlying rocks, though this bore-hole, produced by nature, penetrates to depths of half a dozen miles or more. The lavas ejected by the volcanoes of oceanic islands are mostly basic; are there found any rocks of a continental type included in the ash and lava which would lead us to suppose that the base of the volcano is of the same nature as that of the continents?

In Ascension, Darwin records in his *Observations on Volcanic Islands*, that, in the neighbourhood of Green Mountain, fragments of extraneous rocks are frequently met with embedded in the midst of scoriæ. They nearly all have a granitic structure, are brittle, harsh to touch, and apparently of altered colours; that is to say, they have been intensely

heated in their passage to the surface. Among the rocks so occurring Darwin records a white syenite streaked and mottled with red, consisting of well-crystallised felspar, numerous grains of quartz, and brilliant though small crystals of hornblende; secondly, a brick-red mass of felspar, quartz, and hornblende; and thirdly, a large fragment of a conglomerate made up of small pebbles of granite, cellular and jaspery rocks, and hornstone-porphyry, embedded in a base of wacke.[1] Renard, in examining the *Challenger* rocks brought from this island, records hornblende granite, granitite, diabase, and gabbro, torn up from the depth by eruptions of basalt and trachyte. Ascension, as we saw, was a truly oceanic type of island according to the pendulum measurements, yet the floor on which the cone rises must be composed of granite, jaspery rocks, and slate conglomerate.[2]

In the Cape Verde Islands Doelter found continental types of rocks; compact limestones, crystalline schists, syenite, foyaite, diorite, and diabase, in St. Vincent, St. Thiago, and Mayo.[3]

In the St. Paul's rocks, a lonely reef lying on the equator in the very centre of the Atlantic, there is found serpentine which Darwin took to be an alteration product from volcanic peridotite.[4] Renard, however, pointed out that crystals of olivine in it are drawn out and bent upon themselves in the form of a V, in such a way as to strongly suggest that the rock is a metamorphic one which has undergone mass-flowage under pressure.[5] Neumayr, though admitting that the island lies in the tract notorious for submarine eruptions, between long. 20°-22° E. and lat. 0° 30′ 5″, sustained Renard's contention,[6] though Wadsworth [7] and Geikie [8] supported the volcanic

[1] C. Darwin, *Observations on Volcanic Islands*, 1851, p. 40.

[2] A. Renard, "Report on the Petrology of Oceanic Islands," *Challenger Reports, Physics and Chemistry*, vol. ii. pt. 7, p. 62.

[3] C. Doelter, "Spuren eines alten Festlandes auf den Cap Verdischen Inseln," *Verh. k. k. geol. Reichsanstalt*, Vienna, 1881, p. 16; *Die Vulkane der Cap Verden*, Graz, 1882.

[4] C. Darwin, *Observations on Volcanic Islands*, 1851.

[5] A. Renard, "Petrology of St. Paul's Rocks," *Challenger Reports*, p. 15.

[6] W. Neumayr, *Erdgeschichte*, Leipzig, 1890, p. 199.

[7] M. E. Wadsworth, *Science*, vol. i., 1883, p. 590.

[8] A. Geikie, *Nature*, vol. xxvii., 1882, p. 25.

origin. The question of the entirely volcanic origin of these rocks is therefore still matter of dispute.

At Tristan da Cunha, a volcanic island in the centre of the Atlantic between Cape Town and South America, granite blocks have been found, and Carmichael recorded coarsely crystalline rocks lying about the table from which the central cone rises, which had been ejected from the interior of the mountain.[1] In the far south the Gaussberg rises as an isolated basalt cone from the sea at the edge of the ice-barrier of the Antarctic. There are no tuffs, but embedded in the lava there are large boulders of granite and gneiss. The dark constituents, biotite and probably hornblende, are altogether melted away; the lighter materials, quartz and felspar, are also affected and altered by heat, but still remain *in situ*. Into the cavities which the melting of the dark minerals has left, the glassy lava has penetrated, and occupies the original spaces of the crystals by a sort of pseudomorphism. Granite and gneiss boulders lay plentifully about the summit of the mountain, showing that the inland ice once covered it. It is hence not quite clear whether the blocks in the lava have been brought up from the throat of the volcano or are simply surface blocks entangled in the molten mass; the intensity of the alteration by heat, however, suggests the former explanation.[2] It is interesting to recall in this connection the early experiments of Sir J. Hall on the basalt of Arthur's Seat, near Edinburgh. At 100 of Wedgwood's pyrometer (about 920° C.) the whole was changed to a pure black glass, but at 60 (about 760° C.) the felspar remained unchanged, while the augite disappeared and formed a glass along with the base of the stone.[3]

In the Pacific the Solomon Islands contain extensive areas of quartzites and schists; a coarse hornblende gneiss

[1] E. H. L. Schwarz, "The former Land Connection between Africa and South America," *Journ. of Geol.* vol. xiv., 1906, p. 81.

[2] E. Philippi, *Veröffentlichungen des Inst. f. Meereskunde*, Heft 5, 1903, p. 126.

[3] J. Hall, "Experiments on Whinstone and Lava," *Trans. Roy. Soc. Edinburgh*, 1798.

occurs at Thousand Ships' Bay in Vulavu, crystalline limestone in Guadalcanar and Ysabel and jasper at Guadalcanar and Vulavu. In the New Hebrides, gneiss and crystalline limestone occur at Malicolo and Espiritu Santu, and serpentine, like that at St. Paul's rocks, at Aneityum.[1]

In the Fiji group, which rise from a base 2000 fathoms deep, Woolnough has found slates, quartzites, quartz-diorite, and old sedimentary rocks of an indeterminate age, underlying the volcanic superstructure. At Nasogo there is a tufaceous conglomerate containing well-worn pebbles of granite, with tertiary fossils embedded in the matrix.[2]

Still farther in the Pacific are the Tonga or Friendly Archipelago, distant 2000 miles from the mainland of Australia. In one of the group, Ena, Lister records finding a boulder which Harker determined as uralitised gabbro in the tuffs there are numerous crystals of garnet and tourmaline, which Lister rightly points out must have come from some crystalline schists.[3]

Wherever we make a close search in oceanic islands, there traces of a continental crust of low specific gravity are found far more work must be done before we can make a comprehensive statement on the subject, but everything that has been discovered is totally adverse to the theory that the ocean floor is made of materials different from those of which the continents are made. We can attack the question from two other points of view; we can ask, are there evidences of continents having foundered where now the ocean lies and secondly, are there evidences that the tectonic features of the land are continued into the ocean?

For the first of these I will take the case of the Atlantic. There are other tracts of ocean that could be taken, such as the Lemuria or Gondwana land, connecting India and Africa of which the Seychelles and Comoro Islands are, as it were

[1] W. Guppy, *The Solomon Islands, their Geology and General Features* London, 1887.
[2] W. G. Woolnough, "The Continental Origin of Fiji," *Proc. Linn. Soc. N.S. Wales*, vol. xxviii. p. 457.
[3] J. J. Lister, *Quart. Journ. Geol. Soc.* 1891, p. 600.

stepping-stones still left unsubmerged; there are also the land connections of Australia with the Asiatic continent which Wallace has described so admirably, and there are also the past connection of Australia with South America. But none of these cases allow of the compactness of treatment with which the connection of Europe and Africa with America, across the Atlantic, can be described, and it will be sufficient for our argument if we take one case in detail.

In the North Atlantic there is just one stepping-stone left of all the mass of land sunk beneath the ocean. It is the tiny Rockall Island lying 240 miles from the nearest point on the Irish coast, 290 from Scotland, and 170 from St. Kilda. It is about 250 feet in circumference at its base, and about 70 feet in height. At a radius of $2\frac{1}{2}$ miles from the rock the depths are from 40 to 70 fathoms; but within that area two other small rocks rise nearly to the surface of the sea. Haslewood Rock is a small half-tide detached rock, $1\frac{1}{2}$ cables from Rockall, and Helen's Reef, $1\frac{3}{4}$ miles from it, is covered by about 6 feet of water at low tide. Minute as it is in size, Rockall is exposed to the full swell of the Atlantic, which rises and falls here more than twelve feet in the calmest weather. The east face is a great slab of grey granitoid rock, with rectangular joints broken off at the north, so as to show the square edge of another slab, and this in turn is torn off, showing the face of a third, and so on. This granitoid rock rests on one showing a kind of bedding dipping about east at an angle of 30° or so. Three specimens of rock were submitted to Prof. Judd for examination; in each case they were obtained by a sailor, with a line attached to him, springing from a boat on to the rock, and when he had secured fragments of it, throwing himself into the sea to be towed back to the boat. Two of the specimens were augite granite with apatite, magnetite, arfvedsonite, and a blue soda-amphibole; the third is a dyke rock.

If we look at the structural geology of Cornwall, Devon, and the South of Ireland, we shall notice that the main lines of the older rocks sweep westwards first in a direction W.N.W.

and then due west. These folds belong to what Suess has called the great Armorican arc; the earth's crust was compressed in former times, so that the crests of the folds coming westwards from Europe took the above-mentioned directions; how far westwards they originally extended, we cannot tell; they are cut off abruptly at the coast. That the earth must have been folded far out into where now the waters of the Atlantic lie is an unquestioned fact, and folding means sedimentation, and sedimentation means continental conditions in the neighbourhood. If now we look on the other side of the Atlantic, in Nova Scotia and Newfoundland, the same folds running as if in continuity with those of Great Britain are found traversing the older rocks. The coincidence is so striking that one cannot escape the conclusion that these folds on either side of the Atlantic are the ends of a great chain of folded mountains which once stretched across the North Atlantic as dry land, and comparable to the great chains of folded mountains in Central Asia.

I have already referred to the fact that the Cambrian sediments in the west of Great Britain indicate the near neighbourhood of a large land area to the west; in Merionethshire they are 12,000 feet thick, in Shropshire 3000 feet, in the Malvern Hills 800 feet; these are the rapidly accumulating arenaceous sediments. Farther out the muds are distributed more slowly and more evenly; in Scandinavia the Cambrian sediments are 290 feet thick, although all the separate stages and subdivisions in England are represented. The same is found in the Silurian system. In the lake district of England it is 15,000 feet thick; in the island of Gothland, in Sweden, it is 208 feet, again with all the English subdivisions represented. These facts point to a large continent, lasting through vast periods of time, pouring its debris, by means of its easterly flowing rivers, as sediment over the floor of the sea, where, long years afterwards, the continent of Europe was born from the waves, and the Cambro-Silurian continent in the Atlantic disappeared in its turn. We can trace the remains of the sediments carried by the easterly flowing rivers; but we do

not know where the sediments carried by the westerly flowing rivers are; they may be in America, or they may be under the Atlantic, but what is certain is that vast continental areas of rocks and sediments must underlie the North Atlantic. Turning now to the South Atlantic we find many evidences of a vast land mass having once occupied the space where now water lies; this has had many names applied to it. It was called by Plato, together with the northern land mass, Atlantis; Aristotle called it Antilla, and the northern tribes called it Brazil. In legend there are the tales in Portuguese of the Island of Gomera, and St. Brandan, the Scotch abbot, is said to have landed on such an island. More recently it has received the name of Archhellenis from Ihering; the Atlantico-Aethiopic continent from Katzer[1]; and I have referred to it as Flabellites land, because along its southern and western shores there lived a peculiar little shell, *Leptocœlia flabellites*, which is known from nowhere else.[2]

These shore deposits are very characteristic; we find them all over the west of Cape Colony, where they are called Bokkeveld and Witteberg beds. From Darwin's description of the Falkland Islands one can recognise the same features as occur in South Africa, and when Rupert Jones first received the South African fossils from these beds, he at once wrote out to Bain that they were identical with those brought home from the Falkland Islands by Darwin. Subsequent investigation has brought the resemblance still more to the front, not only in the Falkland Islands, but in the Argentine, Brazil, and Bolivia; not only *Leptocœlia*, but the whole series of shore-dwelling forms of animals are remarkably alike. In New York, Hall and Clarke have described many of our South African fossils as occurring there, the latter author, to whom I submitted a series of South African *Leptocœlia flabellites*, found on comparison with the New York species that they were not only identical, but were preserved in the

[1] F. Katzer, "A fauna devonica do Rio Maecuru," *Bol. d. Museo Paraense*, vol. ii., 1895, p. 237.

[2] E. H. L. Schwarz, "The Rocks of Tristan da Cunha," *Trans. S. Africa Phil. Soc.* vol. xvi., 1905, p. 19.

same way in the same kind of rock, and as characteristic of the American beds as they are of the South African.[1]

In rocks of similar age in Europe, that is, the lower Devonian, the fossils are entirely different; we cannot escape the conclusion, therefore, that in those times there was a vast continent which exposed a continuous shore-line from South Africa to the Falkland Islands, and then northwards through South America to New York, shutting off entirely all connection with a northern ocean, which lay where Europe and North Africa are now situated.

Neumayr and Blanford have set out the facts for the case in full; from the distribution of plants and animals, the great land connection between Africa and South America lasted up till comparatively recent times. Such characteristic South African plants as the Proteas are found living in South America; Blanford[2] and Boulenger[3] have noted that among fresh-water fishes the important families of *Chromididæ* and *Characinidæ* are almost entirely confined to these two continents; among the lung fishes, *Lepidosiren* and *Protopterus*, the one South American, the other South African, are the only representatives of the group. Among lizards, the genera of the group *Amphisbænidæ*, *Amphisbæna*, and *Anops*, are represented in both the southern continents bordering the Atlantic, while the northern genera are unrelated. Branner has found *Amphisbæna* in the lonely island of Fernando de Noronha. To understand the significance of this distribution, it should be remembered that the *Amphisbænas* lead an entirely subterranean life, burrowing like earthworms in ants' nests and manure heaps; they are not forms that could be wafted on

[1] See F. R. C. Reed, *Annals of the S. A. Museum*, vol. iv. pt. 3, 1903, pt. 6, 1904; vol. viii. pt. 14, 1908; see also P. Lake, *ib.* vol. iv. pt. 4, 1904, in which works the immense bibliography of the subject is given from the South African point of view. I have to thank Mrs. W. L. Allardyce for sending me in exchange a collection of Devonian fossils from Pebble Island in the Falkland Islands; there are no differences in regard to the species, or the matrix they are in, between these Falkland Island fossils and those of the Bokkeveld beds of South Africa.

[2] W. F. Blanford, "Pres. Address," *Geol. Soc.* London, 1890.

[3] A. C. Boulenger, "Pres. Address," Zoological Section, *Rept. Brit. Assoc. for Adv. of Sc.* S. Africa, 1905.

driftwood from shore to shore, nor are their eggs small enough to be carried adhering to the feet of birds, like those of fish can be. Unless, therefore, there has been a continuous land-bridge between Africa and South America, it is impossible, short of spontaneous generation on the two continents, to conceive how the *Amphisbænas* came by their present distribution. Ortmann[1] and Pocock[2] have examined the fresh-water crustaceans and spiders respectively, and Scharff[3] other groups of invertebrates, and they all show that South America and Africa are practically one biographical province.

In Permo-Triassic times all the southern continents were

Fig. 16.

The distribution of the Amphisbænidæ, after Gadow.

joined by land-bridges, for we find, succeeding the Southern Ice age at the commencement of that epoch, beds characterised by a peculiar flora, of which *Glossopteris* is the most striking example; there were peculiar reptiles, too, in those times, whose remains so far have been found only in South Africa, India, and Russia. With all that has been written about these beds, however, I cannot grasp any leading facts which clearly point to any definite conclusions; rearrangement of land surfaces we know were going on in those times, but the evidence is as yet too confused to say on what particular lines they were carried out.

Leaving this aside, from other evidence we must conclude

[1] Ortmann, *Proc. Am. Phil. Soc.* vol. xli. 1902, p. 267.
[2] Pocock, *Proc. Entom. Soc.* 1903, p. 340.
[3] Scharff, *Proc. Roy. Irish Acad.* vol. xxiv.

that the bed of the Atlantic has been raised above the level of the sea as dry land. In Cambro-Silurian times, in Devonian times, in Permo-Triassic times perhaps, and in Jurassic and Cretaceous times according to Neumayr, vast tracts of land existed in the centre of the ocean. We need not infer that this Atlantis existed continuously throughout this period; judging from what we find on land, which we know has been submerged and has emerged from the sea many times during the geological history of the globe, we should rather conceive the ocean floor to have been subject to the same vicissitudes, and to have sustained an elevatory movement when the continents became submerged, and *vice versa*. All we can learn from these investigations points unmistakably to the fact that the ocean floor is identical in composition with that of the rest of the earth's rock surface.

In regard to the structural features of the land being continued under the sea, we have the remarkable difference between the Atlantic and Pacific types of coast, as established by Suess, which bears out in full the conception of the ocean basins being foundered continents. In the Atlantic the outside of the folds is presented to the sea, that is to say, the older rocks are on the coast and the younger inland, whereas in the Pacific the reverse is the case. The folds of New Zealand, which meet in a schaarung or syntaxis in South Island, can be paralleled with the schaarung of the coastal ranges of Cape Colony in the south-west, only that the *Glossopteris* beds are, in New Zealand, facing the ocean, and the Archæan towards Australia, whereas in South Africa the karroo beds with *Glossopteris* are inland and the Archæan on the coast. We have already dealt with the evidence afforded by the Armorican arc. Instances could be multiplied indefinitely. I will, however, take only one other.

The centre of Japan is traversed by a gigantic line of fracture, called by Naumann the *Fossa Magna*;[1] situated along it are the volcanic range of Shichito and the volcanoes

[1] Ed. Naumann, *Neue Beiträge zur Geologie und Geographie*, p. 16; Fujisan, *Jahresber. geogr. Ges. München*, 1887, p. 109; E. Suess, *The Face of the Earth*, Eng. trans. vol. ii. 1906, p. 179.

Oshima, Amagi-san, Hakone-yama, Ashidaka-yama, the sacred Fuji-yama (12,400 feet), Yatsuga-taki (9114 feet), Rengisan (9800 feet), and Tate-yama (9400 feet), with a granite base. For nearly 800 miles south of Japan this same line is continued out into the sea with the volcanic islands of Hachijo, Bayonnaise, Volcano Island, Torii Shima, Lot's Wife, Rosario, Iwo or Sulphur Island, Nii Shima and San Augustino.[1] The Parry group, Bonin and Bailey Islands form a parallel chain in mid-ocean. The whole structural features of Japan point to the continuation of the strike of the ancient folds out into the ocean along this line of fracture, and since the *Fossa Magna* is bordered by granite, gneiss, and crystalline schists, it is a fair inference that the same rocks border the fracture in the ocean 800 miles out in the Pacific; the volcanoes that rise from it belong to one family, and those on the land, with granitic bases, eject the same lava as those far out in the ocean.

[1] Nii Shima is a new island which was thrown up on November 14, 1904. At first a little island appeared amidst smoke. Later it seemed as if there were three islands. On December 12, instead of three islands, one large island was seen standing in the sea. From day to day this changed in its configuration and those who watched it were anxious what might happen next. To allay alarm and find out what had occurred, ten men set out in a thirty-foot boat and a canoe. They reached the island on February 1, and placed on its summit a flag with the inscription, "New Place, Great Japan, Many Banzais." The south coast is a precipitous mass of rock, while on the north there is a boiling lake. The island is 480 feet high and 2½ miles in circumference (*Geogr. Journ.* vol. xxv. 1905, p. 531).

CHAPTER XII

PRESSURE

THE reasoning we have adopted brings us nowhere in greater conflict with current theories than in the discussion of the result of pressure within the earth. The experiments of physicists are so definite that I should despair of ever reconciling observed fact with laboratory experience, were it not for one great flaw in all these calculations, which is, that nature deals with ranges of temperature and pressure far greater than can be compassed by artificial means. Just as with mass and matter, when the laws of the very small are found to be entirely unrelated to the laws governing the very great, so the results obtained from the furnace and compressor in the laboratory probably have no bearing on the results obtained in the interior of the earth.

The primary law relating to the pressure and density within the earth is that of Laplace, who assumed that the two were interdependent and that the increase of density varied as the square root of the increase of pressure; at the same time, on the Helmholtzian theory of development of heat by self-compression, the temperature rose proportionately. The following table given by Chamberlin and Salisbury in their standard work on *Geology* states the case succinctly, giving the pressure, density, and temperature at various points of the crust from the centre to the circumference, as computed according to Laplace's Law. A temperature of 0° C. is assumed at the surface of the earth.

Computed Pressures, Densities, and Temperatures within the Earth's Crust Based on Laplace's Law[1]

Distances from earth's centre.	Pressure in atmospheres (approximate).	Density.	Temperature in degrees C.
1.00 radius	...	2.8	0
.90 ,,	215,000	3.95	1,110
.80 ,,	510,000	5.13	3,470
.70 ,,	874,000	6.28	6,350
.60 ,,	1,289,000	7.38	9,360
.50 ,,	1,727,000	8.39	12,250
.40 ,,	2,154,000	9.26	14,840
.30 ,,	2,535,000	9.98	17,000
.20 ,,	2,836,000	10.51	18,610
.10 ,,	3,029,000	10.84	19,610
Centre	3,095,000	10.95	19,950

Pfaff[2] very rightly points out that if these figures mean anything we have no cause to postulate any difference in composition between the earth's crust and the earth's interior, since the pressure alone will account for all anomalies of density and rigidity.

Arrhenius, however, allows 80 per cent iron and 15 per cent rock magma to exist in the interior of the earth, but he argues that these must be in the state of a solid gas. The reasoning adopted is, that many substances become less fusible as the pressure increases up to a certain point, when the reverse is the case; thus dimethylethyl-carbinol becomes less and less fusible up to 4750 atmospheres; at higher pressures the substance remains a gas. But the difference between a gas, a liquid, and a solid are essentially the manner in which they can adapt themselves to stresses. From the experiments on isopentane it can be calculated that at the pressures existing in the earth at a depth of 1000 kilometres this gas would be comparable to steel in its rigidity. Arrhenius therefore imagines the interior of the earth to be a gas under sufficient pressure to render it as rigid as a solid; that is to

[1] A. C. Lunn, in T. C. Chamberlin and R. D. Salisbury, *Geology*, vol. i. 1905, p. 539.

[2] Pfaff, *Allgemeine Geologie als exacte Wissenschaft*, p. 42.

say, 95 per cent of the earth is gaseous, 4 per cent liquid, and 1 per cent solid crust outside.[1]

The whole reasoning can be turned in the reverse direction by taking different substances. Barus, taking a rock this time for experiment, showed that the melting point rises continuously with the pressure, and that at the centre of the earth, where the pressure amounts to three million odd atmospheres, the temperature that would be required to melt it would be 76,000° C., or some four times that which is supposed to exist there.[2] Hence the centre of the earth would be unmelted rock even at the enormous temperature calculated. We have no right to assume that because certain carbon compounds reverse under extreme pressures, the same applies to rock silicates.

Reasoning by extrapolation is little better in such cases than assuming that because ten men can build a given wall in ten hours, and a hundred men could build it in one, therefore 360,000 could build it in a second. What we do not know in these cases in nature is whether the molecular architecture is destroyed under immense pressures, or whether on a large scale arch and girder arrangements do not come into play, which would allow for the support of these stresses without loss of state.

Observed facts all tend to show that the earth is solid and rigid right through; that it is cold. On the other hand physicists cannot show any reasons for assuming it is otherwise which are not subject to grave doubts, or which are not contradicted by other assumptions based on laboratory experiment. Until, therefore, better evidence is adduced than that which is at present available, it cannot be objected that we are straining plain facts too much if we just accept them as they are and build up our reasoning upon them.

Pressure, we know, loosens the boundaries of solids and allows their molecules to wander into liquids such as water,

[1] Sv. Arrhenius, "Zur Physik des Vulcanismus," *Geologiska Foreningens i Stockholm Forhandlingar*, vol. xxii. 1900, p. 395; *Geol. Mag.* vol. iv. December 5, 1907, p. 173.

[2] C. Barus, *Am. Journ. Sci.* 1893, 3rd ser. vol. xlv. p. 7.

and indeed, with the help of water, pressure alone is able to convert a solid into practically a liquid without any high temperature; the evidence in the rocks is plain. But steady pressure, without differential movement, is incapable of producing any effect in the alteration of rocks, and we have seen reason to believe that movement is confined to the surface of the globe. The transverse or distortional wave of earthquake shocks is believed to come through the earth's nucleus, but the fact has still to be proved; otherwise the centrosphere is now motionless, the gravitational pull of outside bodies having effect only on the outer crust. It is doubtful, therefore, whether pressure is effective below the earth's crust, that is to say, the earth's centre is solid and the molecules of which it is composed have been packed in the closest possible manner, and remain under mass static conditions in such an arrangement that the effective pressure within the whole is uniform. This is borne out by Oldham's deductions from earthquake investigations, only Oldham assumes an inner nucleus within an outer.[1] These two portions of the centrosphere, the inner one being of the radius of the globe and the outer shell having a thickness of the radius of the globe, must, if his interpretation is correct, be of uniform nature throughout. In other words, although the inner core is more dense than the outer shell, and therefore the molecules must be in a state of closer packing, nevertheless earthquake shocks traversing the outer shell find it equally dense in all directions. Had pressure been effective, and had there been an increase of pressure according to the depth from the earth's surface, then there should be a difference in the rates of the earthquake shocks according as the wave traversed deeper or shallower portions of the outer centrospheral shell. This not being so, we have direct evidence that the theory of Laplace, that the pressure increases with the depth, does not hold within the earth.

[1] R. D. Oldham, "The Constitution of the Interior of the Earth as revealed by Earthquakes," *Quart. Journ. Geol. Soc.* vol. lxii. 1906, p. 471.

CHAPTER XIII

COLD VOLCANOES

VOLCANOES, on the theories we are discussing, are due to pressure and frictional heat developed along lines of movement in the earth's crust. This is not a new idea, being, indeed, Hilgard's modification of Mallet's hypothesis,[1] but we shall bring new facts to bear on the question. In view of the clearness with which the evidence is presented in South Africa, I shall describe in detail the fold-basins of Baviaan's Kloof in Cape Colony, since what has been written about them has appeared in Government Reports and Proceedings of South African Societies not readily accessible; but I shall compare with them the great Ries cauldron, and similar valleys surrounded on all sides with mountains in Würtemberg and Bavaria, and finally I shall show how these cold volcanoes support the assumption of a solid globe.

In the original statement of the planetismal hypothesis, Chamberlin supposed that the heat caused by pressure in the earth's centre melted up certain portions which happened to have low melting points; then stresses arising from the attraction of the sun and moon caused a kneading movement in the earth's substance, by which these local spots of fusion were gradually worked outwards.[2] Hence arose liquid threads or tongues, which, coming from the interior at high temperature

[1] Robert Mallet, "Volcanic Energy, an Attempt to Develop its true Cosmical Relations," *Phil. Trans. Roy. Soc.* vol. clxiii. 1873, p. 147; E. W. Hilgard, *Am. Journ. of Sci.* 3rd ser. vol. vii. p. 535, and *Phil. Mag.* 1874, p. 45; Rev. O. Fisher, "Mr. Mallet's Theory of Volcanic Energy Tested," *Phil. Mag.* October 1875.

[2] T. C. Chamberlin and R. D. Salisbury, *Geology*, vol. ii.; *Earth History*, London, 1906, p. 105; T. C. Chamberlin, *Year Book* No. 3, Carnegie Institution, 1905, p. 208.

to the outer edge of the sphere, which was cold, carried with them a certain surplus of heat above that required to maintain their liquidity in the new horizon. This surplus then became available for melting or fluxing the rocks in the vicinity; the original molten magma thus became a mixture of different kinds of materials. Some of it found its way to the surface as lava when the release of pressure allowed the escape of gases with explosive violence; other portions of it, again, formed bosses, laccolites, and flat-headed dykes within the earth's crust; and such we know frequently to occur, having been subsequently bared by denudation.

This theory falls to the ground if we assume that the earth's centre is cold. I do not for a moment insist that the cause for the production of molten rock which I advocate in this chapter is the only one, and that Chamberlin's explanation or the current theories are entirely wrong; what I do wish to show is that all the phenomena of vulcanology are explicable on a cold earth theory, and the logical consequences of accepting the planetismal hypothesis, if accepted in its entirety, necessitate such explanations.

In dealing with volcanoes there are two types which must be clearly understood before we can proceed with the subject. The first type is that to which most of the known volcanoes conform. There is a chimney torn through the earth's crust by explosive action of gases, exactly as the tubes were torn through the steel shells filled in with dynamite which Daubrée exploded, or those drilled by dynamite fumes in granite as exemplified in the same author's experiments.[1] Then this shattered mass from the chimney or throat is thrown out as a cone round the orifice. Next lava rises; the diminished pressure and heat causes the water-vapour and other gases occluded in the molten magma to escape with explosive violence, the head of the lava column is blown off and the white hot material is shot high into the air, where it cools as

[1] A. Daubrée, *Les Régions invisibles du globe et des espaces célestes, eaux souterraines, tremblements de terre, météorites*, Paris, 1892, p. 154; *Études synthétiques de géologie expérimentale*, Paris, 1879, pp. 639 *et seq.*

ash and falls round the orifice to build up the ash cone, as in Vesuvius, Etna, Fuji-yama, and the Andean volcanoes. Next, lava, with most of the occluded gases escaped, rises quietly, fills in any crevices with dykes of lava, and eventually breaks a way over the crater or central opening and flows down as a stream of lava. Lastly, the column of molten rock, no longer driven upwards, solidifies in the chimney, and the enormous heat acting upon the rocks surrounding it, causes vapours of sulphur, carbon dioxide, and water to issue continuously in solfataras and fumaroles for many years, the pyrites and

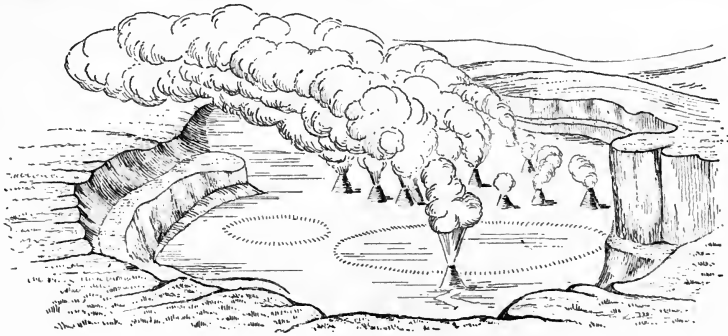

FIG. 17.
Kilauea, Hawaii (Ellis, 1825).

limestone of the rocks and water held up in their capillary and sub-capillary interspaces affording the supply.

The other kind is the caldera of Dutton [1] exemplified by the lava lakes of the Hawaiian Islands, of which Kilauea and Mauna Loa are the types. These are hollows 3 to 3½ miles in greatest diameter occupying holes in the earth; the walls bounding them are cliffs formed by the breaking away of the normal rock of the country, and there is no elevation in the land outside them, such as scoriæ heaps or the massed streams of lava. The depression is occupied by a solidified sheet of lava, which during eruption wholly or partially disappears, exhibiting the cherry-red molten rock

[1] C. E. Dutton, "The Hawaiian Volcanoes," *Fourth Ann. Rept. U.S. Geol. Survey*, 1883.

beneath. The shape of the hollow is continually changing; the cliffs break away or are undermined, and large and small blister cones come into being as the new covering of solid lava forms over the liquid column. The lava does not overflow the bounds of the sunken area, at least in the examples known, and the surface of the earth is only enriched by the small amount of ash thrown out by the blister cones, Pele's hair, the threads of lava drawn out by the rising gas bubbles

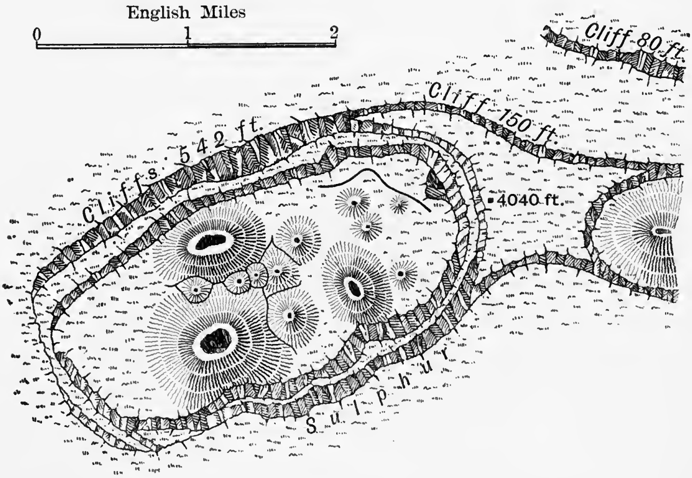

FIG. 18.
Kilauea, Hawaii (from Dana, after Lieut. Malden, R.N., 1825).

and blown away by the wind, and to a small extent by the products of fumarolic action such as sulphur.

It has been generally held that the two varieties are due to the manifestation of one and the same set of causes, differing not in kind but in degree. From what we now know of embryonic or crypto-volcanoes, that is to say, volcanoes that have not arrived at a state at which any of the usual accompaniments of volcanic activity are thrown out, such as ash and lava, it would appear that the ordinary type of volcano occurs along pressure zones of more or less linear nature; but the caldera type is due to a screwing motion in the earth's crust resulting from the simultaneous development of pressure

along two different shear planes (Fig. 22). I shall take the second case first.

In the development of a normal fault there is necessary first a stretching in the earth's crust whereby a portion is detached and falls inwards. From this it follows that as a rule a fault in one place, say with a downthrow to the south, must be accompanied somewhere else by a similar fault with a downthrow in the opposite direction—in our example, to the north ; this can be illustrated by pulling an arch apart, when the keystone will fall downwards, reproducing in miniature what happens in the earth on a large scale. Where the two faults are close together, a narrow slip of ground is let down, and on either side there are precipitous cliffs formed by the opposing fault faces. The most magnificent example of this is the great Rift valley of Central and Northern Africa in which Lake Tanganyika lies, and also the Nile Valley and the Dead Sea, as described by Suess, Gregory, Hull, and others. In Egypt, Barron and Hume have shown that there are an immense number of smaller rift valleys in which patches of cretaceous rocks are let down between walls of granite, the former having been removed by denudation from the whole area, except where protected in the hollows of the depressions. In Europe, to cite only one area, the same features may be studied in the Thuringer Wald. The occurrence of crossing faults with closed sunken areas between does not, however, seem to have been noticed, and these throw a great deal of light upon the subject of caldera.

The most commonly known kinds of faults are those with a downthrow or upthrow on one side, that is to say, normal and reversed faults ; but horizontal thrust is quite as frequently met with, only being less obvious, and having no great stratigraphical significance, is frequently overlooked. The best instance of these was actually seen to form during the great earthquake of San Francisco of April 18, 1906.[1] Along old fault lines the earth moved laterally with or without

[1] Stephen Taber, "Some Local Effects of the San Francisco Earthquake," *Journal of Geology*, Chicago, vol. xiv. 1906, p. 303.

uplift on one side, the maximum amount of horizontal thrust being 9 feet; hedges, fences, roadways were cut clean across and one side moved laterally along the shear line. Cracks meeting the fault line at an angle of 45° ran from the fault a quarter of a mile or more, some of them gaping 2 feet or so; these latter show the drag brought to bear along the sides of the fault, and give some indication, occurring as

FIG. 19.
The mouth of the Groot River, Zitzikamma, Humansdorp, Cape Colony, showing the change of strike in the beds of quartzite due to horizontal faulting.

they do in the zone of fracture, what must be the energy converted with heat in the deeper portions of the earth's crust.

It is such horizontal faults which would best produce the rolling motion to which the sunken plugs are due in these pit-faults, fold-basins, or rock cauldrons, whichever term we choose to name them by. It is difficult, however, to conceive exactly how they can be produced simply by either direct horizontal thrust or vertical downthrow; but if the motion is

a vibratory one, as I have suggested, then the crossing fault lines would be represented by wave fronts, and the plugs caught between them would be knots in crossing vibrations. We can see such pits produced in sand marked by crossing ripples. Whatever the true explanation may be, these sunken enclosed areas do occur in nature, and they are definitely the results of faulting which occurs only round the edge and does not pass into the surrounding rocks, and it is equally clear that the faulting is an accompaniment of cross folding. I can best illustrate this feature from the set of these pit-

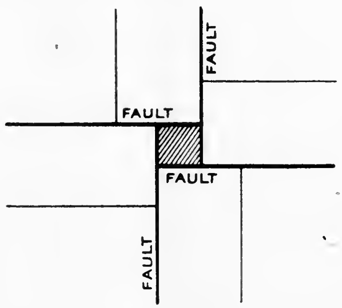

FIG. 20.
Block dropped by crossing horizontal faults.

faults which occur along the Baviaan's Kloof River in the south of Cape Colony[1] (see map, Fig. 21). The country rock is mostly Table Mountain sandstone, a coarse, massively bedded sandstone normally 5000 feet thick. It is folded so that the beds underlying it are exposed on the south, and it dips below the beds lying upon it on the north. The axis of the folds comes almost due westwards from the Cape up to near the western point of Baviaan's Kloof. The beds underlying the Table Mountain sandstone belong to the Pal-Afric group, probably of Archæan age, and are intruded by great bosses and dykes of granite. A little to the east of George the

[1] E. H. L. Schwarz, "Geological Survey of parts of Prince Albert, Willowmore, Uniondale—vii. Baviaan's Kloof," *Ann. Rept. Geol. Comm.* 1903, Cape Town, 1904, p. 119; "Baviaan's Kloof, a Contribution to the Theory of Mountain Folds," *Addresess and Papers, British and S.A. Assoc. for the Advancement of Sci.*, S. Africa, 1905; vol. ii. Johannesburg, 1906, p. 56.

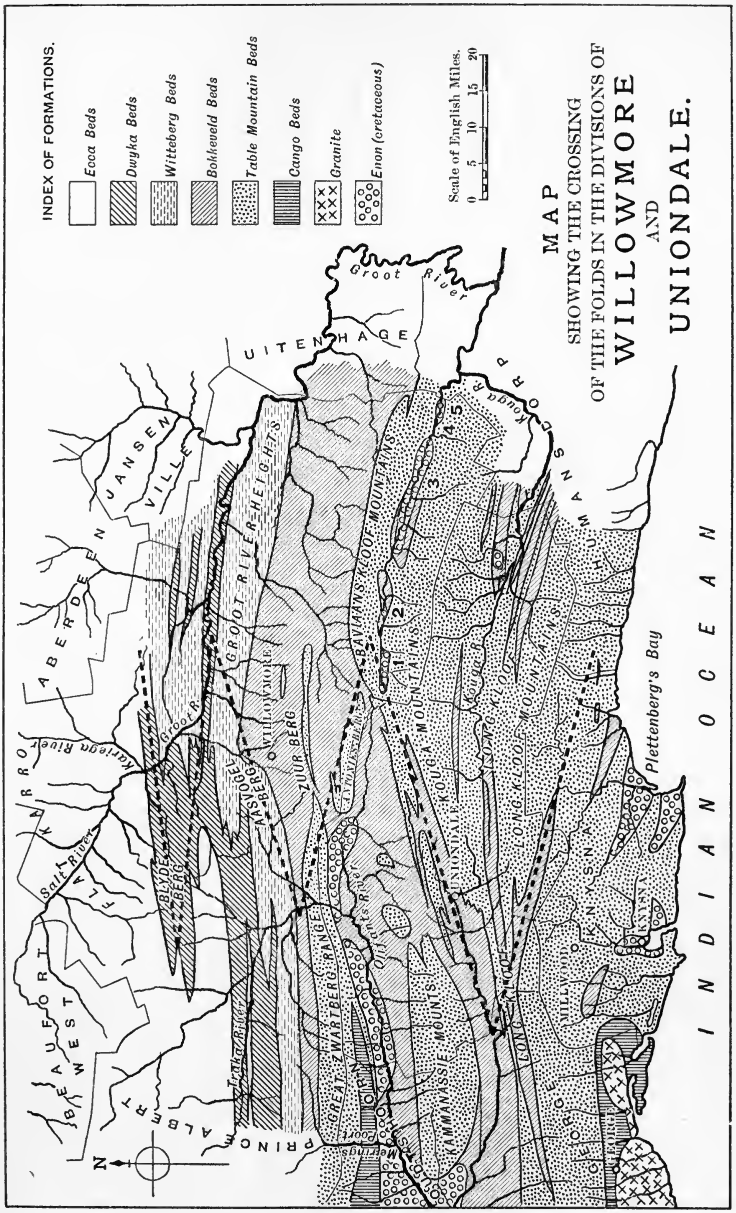
INDEX OF FORMATIONS.
Ecca Beds
Dwyka Beds
Witteberg Beds
Bokkeveld Beds
Table Mountain Beds
Cango Beds
Granite
Enon (cretaceous)
Scale of English Miles.
0 5 10 15 20
MAP
SHOWING THE CROSSING
OF THE FOLDS IN THE DIVISIONS OF
WILLOWMORE
AND
UNIONDALE.
INDIAN OCEAN
Plettenberg's Bay
UITENHAGE
Groot River
JANSEN VILLE
ABERDEEN
KARROO
Kariega River
Salt River
FLAT
BEAUFORT WEST
PRINCE ALBERT
Traka River
GROOT RIVER HEIGHTS
BAVIAANS KLOOF MOUNTAINS
KOUGA MOUNTAINS
LONG KLOOF MOUNTAINS
LONG KLOOF
Kouga R.
Kouga
HUMANSDORP
ZUUR BERG
AASVOGEL BERG
BLYDE BERG
WILLOWMORE
UNIONDALE
GREAT ZWARTBERG RANGE
Olifants River
KAMMANASSIE MOUNTS
OUDTSHOORN
Meirings Poort
GEORGE
MILLWOOD
KNYSNA
N

FIG. 21.

granite comes to an end, and some remarkable phenomena result from the absence from the Pal-Afric beds of the support afforded by these heavy intrusions of igneous rock. Where the granite exists along the coast, the pressure which buckled up the mountains coming from the interior, spent itself against these granite buffers without moving them; the rocks internal to them became intensely compressed with folds whose axes run parallel to the line of granite bosses. East of the granite, the pressure from the interior was not intercepted by insurmountable obstacles; the slates, of which the Pal-Afric beds are mostly formed, gave readily, and the whole earth segment was pushed seawards. Consequently the folds flatten and the axes fan out seawards, a fact which can be readily noticed even in ordinary topographical maps where the mountains are put in correctly. As a result of this movement round the end of the granite, faulting and folding in two directions took place with more or less horizontal thrust, the one set being disposed by the general direction of the granite bosses, and the other by the amount of motion which the seaward thrust of the earth experienced.[1]

As a result a number of well-defined pits, the largest 20 miles in length, have been let down between the crossing folds. These are the fold-basins of Baviaan's Kloof; but similar ones occur throughout the south-western districts of Cape Colony.

The peculiar chain of circumstances which have preserved these fold-basins is a long history of which we can only here touch on the essential features. Before the movement which produced them took place, the land lay 4000 feet lower than it does to-day. The rivers from the interior were arrested at this level, and having no further fall they cut sideways till the whole country was levelled more or less into a plain. Torrents carried great masses of coarse boulders and sand from the mountains on to this plain, and the flow of the rivers was too feeble to carry them away; thus the whole plain

[1] E. H. L. Schwarz, "Geological Survey of the Coastal Plateau in George, Knysna, Humansdorp, and Uniondale," *Tenth Ann. Rept. Geol. Comm.* 1905, p. 47, map; "Gold at Knysna and Prince Albert," *Geol. Mag.* Dec. 5, vol. ii. p. 369.

FIG. 22.

The east end of a fold-basin in Baviaan's Kloof. To the right the Table Mountain Quartzite is seen dipping west, with a little Devonian Slates resting upon it in the bush-covered hill. In the background are seen the fault-faces against which the inclined quartzites abut. Under the spectator the quartzites are dipping north towards the fault-faces, and this dip sweeps round in a semicircle to the right, and is cut off by the fault.

became covered with a thick deposit of boulders, gravel, and sand. Presently level tracts became shut off and covered with blown sand; shallow fresh-water lakes were formed, on the banks of which large Dinosaurs browsed and eventually became buried. Lastly, the level area sank beneath the sea and became covered with sands, muds, and limestones, in which we now find shells of Ammonites, Trigonias, bones of Plesiosaurs and so forth, clearly indicating their age as Lower Cretaceous. These three formations, the gravels, the fresh-water deposits, and marine deposits, are known as the Enon Conglomerate, Wood Bed, and Sunday's River Marine Beds, united under the term Uitenhage Formation.

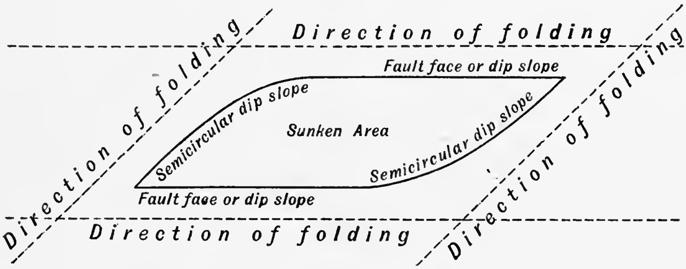

FIG. 23.
Scheme of the Baviaan's Kloof fold-basins.

Now the cross-folding took place, and the cretaceous beds became let down in the deep pits. Then the land rose and vigorous denudation set in which soon washed off the loose cretaceous deposits from the harder and older rocks beneath. But those patches in the pits were left, as the rim of hard rock all round them preserved the loose sediments from being washed away. Many of the fold-basins are in this condition to-day, notably the one at Swellendam, but in Baviaan's Kloof a large river, a branch of the Gamtoos, began to flow along the plain where the fold-basins were, and presently the great fall and consequent erosive power of the river, due to the continuous rise of the continent, caused the river to excavate a deep channel. Where the river ran over the hard Table Mountain sandstone it simply sawed out a narrow

gorge; but where it passed through the fold-basins, the loose deposits readily crumbled and the debris was washed away through the gorges into the sea. As a consequence the fold-basins have been cleared out and reveal with astonishing clearness the sequence of events by which the earth has had these pits formed in it; one can almost imagine them as the work of a gigantic carpenter who has gouged out holes in the earth and plugged them up with soft material.

The depth of the basins is from 800 to 1000 feet, and one stands within them with precipitous cliffs on all sides closing

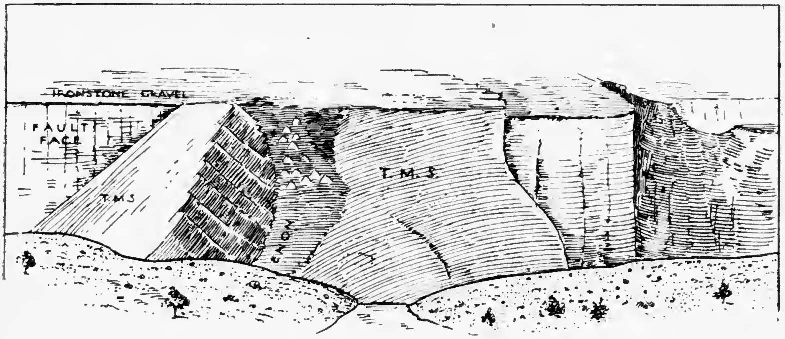

FIG. 24.

View across the east end of the second fold-basin in Baviaan's Kloof, showing the dip-slope abutting against the northern fault face. This view is taken from the top of the 4000-feet peneplain, whereas Fig. 22 is taken half-way up. T.M.S., Table Mountain Sandstone. Enon, Cretaceous gravels.

in the view. As a rule the northern face is a fault face, but in places the effect of the fault is brought about by a very steep downward fold; and in the south, the steep fold is usually the means by which the floor of the depression is let down, though faults occasionally take its place. To the east and west the fold or fault turns round in a semicircle and abuts against the north or south fold. The extraordinary feature of these folds or faults is that outside the rim of the pit there is no evidence, except in one case, of the continuance of the disturbance; the rocks are apparently as solid and unaffected by any such violent distortion as they are in areas where there has been no faulting at all.

On the north fault face there is frequently developed enormous areas of fault breccias. The compact Table Mountain sandstone has been crushed to a fine quartz breccia, much as if it had been passed through a crusher to make road-metal; at other places the grinding has been finer, and I could only compare it to crushed glass. The

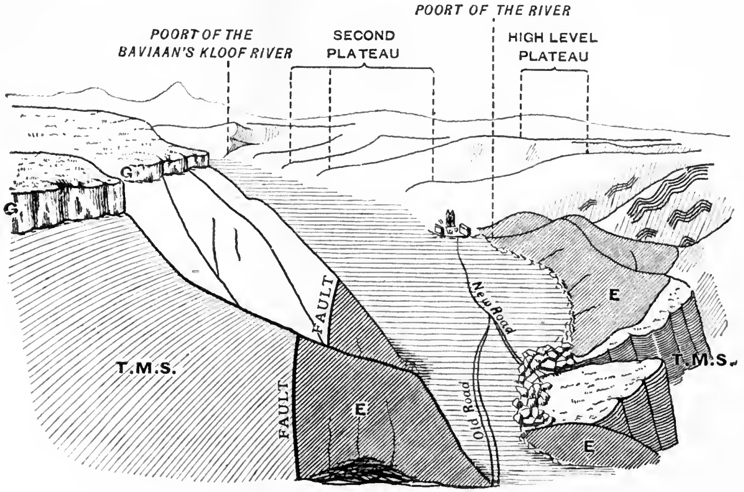

FIG. 25.

The second of the Baviaan's Kloof fold-basins (see Map, fig. 21, p. 175) seen from the west; the dip-slope on the south and the fault on the north are shown. The Poort in the distance is shown in Fig. 24. In the foreground some of the red Enon Conglomerate (Cretaceous) E, is shown still left in the basin; the rest has been cleared out by the river leaving the rock sides of the basin exposed. T.M.S. is Table Mountain Sandstone. The top plateau is 4000 feet above sea-level; nearer the present river bed there are ledges showing a former stage in the excavation of the loose contents. G, silicified sand and gravel resting on the high-level plateau.

crush-breccia is mostly loose and uncemented, forming a terribly harsh surface; at other points, however, water carrying iron in solution has cemented the whole into a ferruginous breccia. The crush-breccia does not occur all along the fault faces but only in certain parts; one of these is 7 miles long, three-quarters of a mile broad, and stands 1000 feet above the river level, though it must extend many times that amount in depth—that in sight alone is more than a cubic mile in volume, and the stupendous force that was necessary

Fig. 26. The Development of a Thrust-plane from a Fold. Table Mountain Quartzite, Prince Albert Pass over the Zwartberg Range to Oudtshoorn

To face page 180

to produce this result can be imagined when it requires a pressure of twenty tons to the square inch to similarly crush a cubic inch of the rock in our testing machines. At the

FIG. 27.
Development of a fold, showing how it may disappear upwards; Meiring's Poort, Oudtshoorn, Cape Colony. The rock is Table Mountain Quartzite.

time of describing these crush-breccias, I pointed out that such a force acting on rocks less resistant to fusion than this pure quartz rock, such as limestones and shales, would be melted. A couple of years later, two volcanic necks filled in with lava and ash were discovered in a similar position—not along this particular line of faulting, but one just to the north

of it, and comparable in all respects to it only that the rocks in the line of fracture were the calcareous glacial muds of the Dwyka conglomerate. We shall return to this point later.

There is a point of general application, which seems obvious enough, but which is not universally appreciated, namely, that there is far more activity a mile or so below the surface than there is on the surface of the earth. A movement of the crust which shows as a fold at the surface may become a fault as it is followed downwards. The reason for this is that the earth's temperature increases as we go downwards for a certain depth, and consequently expansion under high temperature becomes more vigorous the farther the rocks are from the surface. Under such circumstances there must be many more cases of crossing folds within the earth than there are manifest at the surface, and pits and depressions caused by the screw-like motion of the shearing will appear at the surface with none of the faults which are so apparent in Baviaan's Kloof: they will simply be hollows into which the drainage of the country will flow and lakes will be formed.

It is no use theorising on the supposed nature of, say, Lake Constance, which might very well have been formed in this way. Penck thought that perhaps the great deposit of ice brought down from the neighbouring Alps during maximum glaciation in the Ice age would have been sufficient to weight the earth and cause the depression,[1] but a subterranean pit-fault seems to me to explain the circumstances better. We have more definite examples, however, than this: lake basins which have been drained dry and show the features of the Baviaan's Kloof fold-basins in a way that is unmistakable. The first example is the Steinheim basin.

Steinheim is a village in the Swabian mountain region near the Danube. It lies in a circular depression $1\frac{1}{2}$ miles across and 260 feet deep. In the centre there is a hill, the Klosterberg, rising from the floor 132 feet (Fig. 28). At one

[1] "Sollte einer so stattliche Last von 700 Tonnen (von 750 m. Eis) auf dem Quadrat-meter nicht die Erdoberfläche eindrücken und eine Senkung hervorrufen können, welche den See erklären würde?" Albrecht Penck, "Der Bodensee," *Vortr. d. Verein. z. Verbreit. naturwiss. Kennt. in Wien*, vol. xlii. Heft 6, 1902, p. 11.

time it was filled with water, and all round the sides there are deposits of fresh-water limestone and sand belonging to the upper Miocene age, with the shells *Planorbis steinheimensis*, *Carinifex tenuis*, *C. multiformis*, *C. discoideus* and

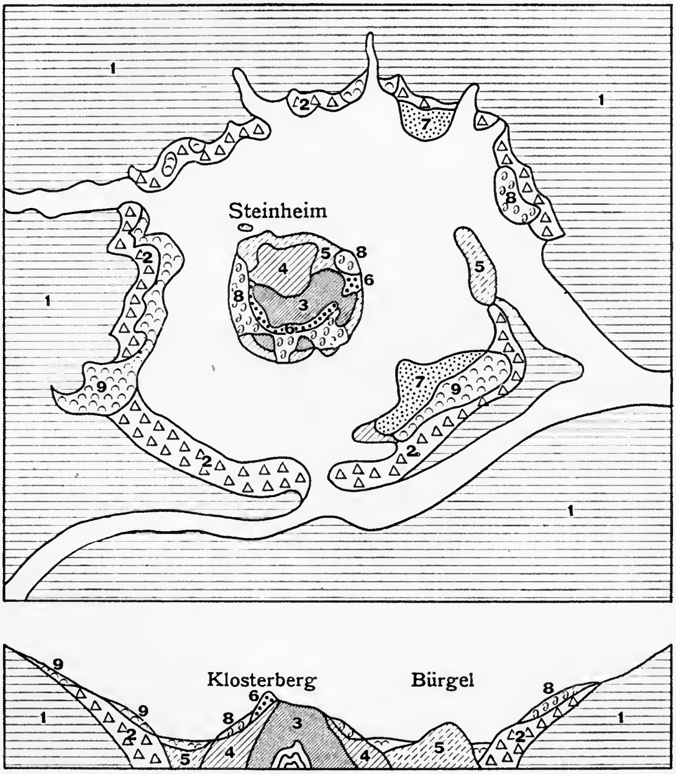

FIG. 28.

The crypto-volcanic basin of Steinheim, after Branço and Fraas. 1. Normal Upper White Jura. 2. Crush-breccia. 3. Crushed Brown. 4. Crushed Lower White Jura. 5. Crushed Upper White Jura. 6. Tertiary travertine. 7. Tertiary sand. 8. Sand with snail-shells. 9. Fresh-water limestone with *Planorbis laevis* Klein.

C. trochiformis. The rim of the basin is formed of the upper white Jura limestone, but in the centre the hill is formed of a dome of the underlying brown Jura with the white Jura concentrically arranged around it; this has been pushed up from below. Round the sides of the basin the limestone has been

brecciated by pressure; the blocks of limestone have the peculiar cone-in-cone fractures which are frequently produced in blocks submitted to intense pressure in testing machines; the embedded belemnites are fractured but not broken to bits, the parts being recemented together, but flint nodules have been splintered. These facts point unmistakably to the absence of brecciation by volcanic explosions.

Branco and Fraas,[1] to whom I am indebted for the above description, ascribe the peculiarities to the action of a rising mass of molten magma, collecting as a laccolite beneath the surface; the first action of this was to raise the central portion and then, on the force of uplift being expended and the molten magma cooling, the consequent contraction resulted in a sinking. There is, however, nothing to support this theory beyond a deposit of calc-sinter from a hot spring which forms the present apex of the Klosterberg, though the two authors above referred to rest their conclusion on a comparison of the Steinheim basin with the Swabian volcanoes, of which they are the highest authorities.

A pit-fault would, however, satisfy all the needs of the case. The crush-breccia round the edge and the considerable compression which resulted in the upheaval of the Klosterberg, would follow naturally from two double faults crossing at an angle. The actual faults may be buried a thousand or more feet before the continuation of them in linear series becomes visible, but the rolling motion would cause the plug caught between them to communicate its compressive upheaval to the surface rocks.

The second of the depressions, the Ries, is of much the same nature, only ten times as large, being 15½ miles in diameter, and is accompanied on the south by a concentric half-moon-shaped depression, the Vor-ries. It lies 17 miles north-east of Steinheim.[2]

The Ries is a circular depression in the white Jura; the

[1] W. Branco and E. Fraas, "Das kryptovulkanische Becken von Steinheim," *Abhandl. d. k. preuss. Akad. d. Wiss.* 1905.

[2] Walther von Knebel, "Studien über die vulkanischen Phänomene im Nördlingen, Ries," *Z. d. deutsch. geol. Gesell.* Bd. 55, 1903, p. 236.

broken edges of the strata in the cliffs, which are from 300 to 350 feet high, are continued in an unbroken line all round. On the north and north-west the brown Jura, Lias, and a little Keuper are exposed. The floor of the depression is covered with Tertiary fresh-water deposits, lying upon granite and crystalline schists with dykes of kersantite (Aschaffite). Round the edge there are evidences of great pressure in the crush-breccias and overthrust of the strata, but this line is often occupied by volcanic ash, tuff, bombs, and similar volcanic ejectamenta. Von Knebel includes among these the rhyolite lava at Amerbach, but there seems to be some doubt whether the igneous rocks belong to the time of the formation of the sinking, or were already in place before that happened. The tuffs are of two kinds. The one consists of a light-green porous ground-mass which has been formed by the pulverisation of a glassy lava. Under the microscope there are seen opaque, earthy patches and transparent glassy ones. Embedded in the mass are small fragments of slaggy, pumiceous, volcanic glass, larger scoriæ and bombs, crystals of orthoclase, plagioclase, and mica, and the whole is cemented with deposits of zeolites, carbonate of lime, and tridymite. There are, however, no signs of sulphur or of the minerals such as augite and olivine, which accompany lavas of a basic type. The second variety of tuff consists of countless fragments of crystalline schists, gneiss, and granite embedded in a red earthy matrix which is often absent; no volcanic material at all is present. This is undoubtedly formed by the explosion of gases working upon the fractured sides of the plug of crystalline schists and gneiss.

The Ries cauldron is, for all its depression, a mountain. The floor of the hollow consists of granite and gneiss, from 300 to 350 feet below the level of the surrounding country. Bore-holes, however, put down outside the Ries only strike the granite at 1300 feet, so that looking at the upper surface of the granite, that in the Ries cauldron is 1000 feet above the rest. In this feature, as Branco points out, the Ries closely resembles the Steinheim basin, and the granite plug

may be conceived to be a plunger, which in the latter case has forced up the strata in the Klosterberg.

Other similar pits are found at Neresheim and between Ellenberg and Bopfingen, the latter 18 square miles in area, and right away at the south-western end of the Swabian mountain-land there is the Hegau cauldron.[1]

The Hegau pit is 11 miles in diameter at the bottom and is purely volcanic, although the surrounding cliffs are similar in nature to that of the Ries. In the centre of the depression there is a group of hillocks consisting of basalt, melilite-basalt, and phonolite. These are surrounded by vast accumulations of tuff as in ordinary volcanoes, and the lava solidified in the chimneys, now that the ash cones have been washed away by rain, stand out as pillars with cliffs 650 feet high. An interesting intermediate stage between the Ries and Hegau cauldrons is shown in many of the great lunar volcanoes, where the smaller cones form a circle round the large caldera and breach the rim (see Fig. 1, p. 22), that is to say, the brecciation round the edge of the central plug has produced, not brecciation, but actual melting; but this has not been sufficient to swamp the depression with lava.

We have, then, in these German fault-pits a complete gradation from a simple depression to one which becomes a field of volcanic activity. Granted that the fault-pits can form in the manner I have described, the question of whether the depression will occur with or without accompanying vulcanism depends on two factors. First, the fusibility of the rocks that sustain the crushing movement, which, if consisting of quartzites, would simply brecciate; or if of shales and limestones or felspar rocks of low melting points, would fuse into a liquid. In both cases heat would be produced: in the first case, only hot springs with a little non-volcanic tuff perhaps would result; in the second case actual glass would be formed, which, from the volatilisation of the water included in the rocks, would be blown out as ash and finally lava would

[1] W. Branco, *Schwabens 125 Vulkan-Embryonen*, Stuttgart, 1894, Ries, p. 162, Hegau, p. 165.

rise. The second factor is the depth at which the features now exposed were formed. At the surface the heat developed by the friction due to the crushing would have to raise the rock from the average temperature at the earth's surface right away through to the melting point, if lava was to be formed; hence we find that in the more recent basin of Steinheim the calcareous sediments are merely crushed without fusion. If, however, the crushing takes place deep within the earth's crust, then the initial temperature being high, only a comparatively slight increase would suffice to melt the rock and give rise to volcanic activity. Then the movement round the sides of the plug would afford passages for the escape of steam, and once that became established a hole or chimney would quickly be drilled by the uprush of water-vapour, and consequently a way would be opened for the molten lava to rise.

A still later stage than the Hegau cauldron is exemplified by the caldera of Mauna Loa and Kilauea, where the continuance of the pit-faulting has resulted in the complete disappearance of the central plug, and as this sank, the molten rock welled up round the edges and filled the whole area of the depression; the cold volcanoes have become hot ones.

Pit-faults of the nature I have described are, I believe, of far more common occurrence than generally supposed. The depressions that frequently accompany earthquake shocks are possibly due to this cause. One such depression is described by Lyell in his second visit to the United States; it lies 10 miles westward of the Mississippi, inland from the town of New Madrid, in Missouri. The area is called the "sunk country," and extends between 70 and 80 miles north and south and 30 or more miles east and west. It was caused by the earthquake of 1811.[1] On the surface such features are remarkable enough; but suppose that the land along the Mississippi were to rise, in the course of ages the loose deposit on the top would be cleared away, the younger

[1] Sir Charles Lyell, *Principles of Geology*, 9th ed. 1853, p. 270.

sedimentary rocks would be exposed and in their turn denuded away, till at last the granite base would be laid bare; then there would be a closed basin with a rim of granite, and what remained of the younger rocks would occupy the interior. These, finally, would be carried away by rivers, as the loose cretaceous rocks in the Baviaan's Kloof fold-basins have been, and there would result a cup or hollow in the granite. I have in mind such a cup, which lies 25 miles north-west of Pretoria in the Bushveld granite;[1] it is only half a mile in diameter, but it is by no means impossible that it may have arisen in the way I have supposed, for faults usually hade towards each other in the depth, so that a large area at the original surface may taper down to the diameter of the Pretoria salt-pan below. The shape of the pan suggests a volcanic neck, but no trace of volcanic rocks is visible. Cohen suggested that the hole was drilled by the explosive action of steam as a preliminary to proper volcanic activity, but there are sufficient reasons to believe that it arose from the same causes which produced the Steinheim basin.

We have now to consider the case of the first or more normal type of volcanoes.

[1] H. Kynaston, "On a Traverse from Pretoria to Pietersburg," *Report Geol. Survey*, Transvaal, 1904, Pretoria, 1905; Plate 1, p. 12.

CHAPTER XIV

NORMAL VOLCANOES

THE interdependence of faults and volcanoes has often been commented upon, the train of reasoning being that the faults afford relief of pressure to rocks in the interior of the earth, which are intensely heated and under the enormous load of the rocks above. Where there is relief, the molten rock partially is forced up by hydrostatic pressure, partially is projected upwards by the expansion of water-vapour included in it.

Why, then, do many volcanoes stop at the stage when only the chimney is formed? If there were molten rock ready to burst up from below, surely a vent ready made would cause the instant uprush of lava; yet in the Drakensberg, in the east of Cape Colony, we find holes drilled down to vast depths, filled entirely with material formed by the explosive action of gases on the walls which consist of granite, sandstone, limestone, and so forth. This non-volcanic tuff, which we have already had occasion to notice in the Ries cauldron, has been blown out in vast volumes, flooding the whole country round with the substance, and yet in one case a particular vent may be plugged up with this material which has fallen back into the vacant chimney, whereas in another, not a mile away, lava has welled up in enormous streams; other chimneys are filled in partially with the granite powder, partly with real volcanic ash, and partly with a thin dyke of lava. In studying these features in the field I could not accept the current explanation, but rather considered the heat to have been developed by earth movements; in some cases the water held up in the rocks was vaporised, but the rock

substance was not sufficiently buried or not sufficiently fusible for the heat available to melt it, and therefore the steam simply blew the shattered rock out at the surface. At other points the movements acted under more favourable circumstances, and melting took place with the extrusion of lava.

The Drakensberg is a range of cretaceous volcanoes that probably represent the extreme end of the great Rift valley, which comes southwards from the Dead Sea and valley of the river Jordan, down the Nile valley, through Lakes Tanganyika and Nyassa. However that may be, the range consists now of heaped-up piles of lava 6000 feet thick, resting on a non-volcanic tuff, the Cave Sandstone. Formerly the volcanoes doubtless had ash cones in their early stages, but the later stages appear to have been occupied entirely with the extrusion of lava of a basaltic type. Much weathering has gone on since they were active, and now only the stumps of the chimneys are exposed. A very large number of volcanic vents have been mapped since Dunn first discovered them, but many more lie buried, swamped by the successive floods of lava, and many more that we can see cannot be classed definitely as vents owing to the lava in the chimneys merging into that of the surrounding flows. Where, however, the neck is not entirely filled with lava, then we can immediately recognise the vent. Most of such vents are occupied by volcanic tuff in which occur boulders of rocks foreign to the country, but known to exist deep down below the surface; these have been torn from the depths, as in the rocks of Ascension and the Cape Verde Islands, and reveal the substructure of the earth. Other necks, again, are filled in with pegs of Cave Sandstone quite indistinguishable from the stratum, 800 feet thick, which everywhere underlies the lava flows where these are typically developed. The Cave Sandstone under the microscope shows quartz grains that have been altered round the edge by development of minute scales of talc, a change which is attributed to the action of superheated steam. Besides quartz, there are abundant grains of microcline which can only have come from the shattering

of a granite, a few grains of tourmaline, epidote, rutile, and zircon, which may have come from granite or from crystalline schists.[1]

The lavas are normal basalts, but the crystallisation is so advanced in a large number that they can be better described as dolerites. The microscopic examination showed that they all belonged to one great family, but the development of crystals followed different lines, and produced different types of rock according to the differences of pressure under which they cooled and to the varying amount of water-vapour held up in the rock. There is nothing, however, to show that the lavas are in any way abnormal, and the causes which produced them must be the same as those which produce basic lavas in other parts of the world in volcanoes of the Hawaiian type, or those of the Andes.

Farther north, along the east of the Transvaal, the same range is continued as the Lebombo mountains with more acid lavas, rhyolites, and andesites, and the causes which produced these must have been the same as those which led to the formation of the basalts in the Drakensberg. What is true, then, for the volcanoes of the latter, may safely be applied to the explanation of volcanoes extruding other types of lava throughout the world. In these other cases the sequence of events usually cannot be so clearly followed, as they are either too young and the cinder cones cover all the internal structure, or they are too old, when all structure has been destroyed by denudation.

We recognise, then, three sub-stages in the development of a volcano before it becomes functional as an extruder of lava. First, it shatters the rocks along the course of the pipe or chimney and the activity may stop there, the vent being filled up with fragments of non-volcanic material. Secondly, the lava may rise a certain distance and the head of the column is blown off by the escaping steam ; if activity stops

[1] E. H. L. Schwarz, "Petrographical Examination of the Volcanic Rocks of Matatiele, Griqualand East," *Ann. Rept. Geol. Comm.* 1902, Cape Town, 1903, pp. 95, 96.

there the vent becomes filled in with ash, lapilli, and bombs formed from the molten material, together with a certain amount of rock torn from the sides of the chimney. Thirdly, a portion of the vent may remain open and is filled with a dyke of lava which becomes solidified, surrounded with ash.

The diamond mines of South Africa belong to a later substage, in which molten rock rose to the surface but did not overflow. They differ from volcanic vents in the Drakensberg in a corresponding stage of development in that the rock which forms the bulk of the material is of a very much greater basicity. The minerals, instead of being augite and lime-soda felspar, consist to a very large extent of olivine and to a subordinate extent of ilmenite, bronzite, garnet, zircon, mica, and diopside. The parent rock appears to have been a pure olivine rock, an iron magnesium silicate, which has incorporated in it other rocks, which have been either entirely melted in it or which still remain as fragments scattered throughout it. In the majority of cases water, percolating below the level of weathering, has acted upon the rock, and has leached out the iron, leaving behind a hydrated magnesian silicate, serpentine, and the iron has as usual descended in solution to enrich the sub-crust. This serpentine breccia is the Kimberley blue ground.

The vents at the surface pierce all varieties of rocks, but in the depths there is always encountered granite, and granite we may take to be the natural lip of the chimneys. The cause for the eruption of this basic magma which accords both with facts and the assumptions on which we are working, is that the crustal movement has resulted in pressure being communicated below the range of normal sediments; below the range of altered sediments, the granite; down to the original rock substance of the centre of the globe. We compare the diamond pipes, in fact, with the extrusion of basalt with metallic iron which occurs in Ovifak, in the island of Disco, in Greenland, although in the latter case the portion of the centrosphere tapped by the fault plane consisted more of metallic iron than the patches tapped by the diamond pipes.

The fault planes acting deep down from the earth's surface on rocks, solid, but under great pressure, melted them. As the movement went on the melting progressed upwards, till the zone was reached where the rocks held water in their capillary and sub-capillary interspaces, and consequently an agent for drilling a hole upwards was secured. The hole was drilled by the escaping steam, and the molten rock, still practically free of water, rose quietly in the chimney and eventually solidified. Immediately the intersusception of water began from the saturated rocks around, and the rock became altered from a pure iron-magnesian silicate to a hydrous-magnesian silicate.

The presence of diamonds in the blue ground follows naturally from such an explanation. If the rocks of the centre of the earth are represented by the average composition of meteorites, then this flow of a portion of the central nucleus outwards must have carried with it an average of 1 per cent of carbon in the form of either free carbon, as carbon oxide, or as hydrocarbons. The actual growth of the diamond crystals seems to have occurred *in situ* in the original blue ground under the new conditions under which the rock was in the pipe of the volcano, otherwise the crystals would have been distorted and broken up in the slow upwelling of the magma under enormous pressure. The change from mass static conditions to mass dynamic conditions rendered the carbon and carbon compounds, which had hitherto lain unaltered, susceptible to change, and under immense pressure and heat the crystals of diamond formed. Then, when the rock became hydrated, the increase of bulk induced fresh movement in the pipe, and the larger ones and the more irregularly shaped ones became broken up and the portions separated.

How, then, came it about that the crust was so thin in South Africa, and nowhere else, that the crustal movement was able to tap the unaltered rocks of the centre of the earth?

The answer lies in the recognition of the stratigraphy of South Africa. The most ancient sediment bearing recognisable fossils is the Bokkeveld series of lower Devonian

age ; below this is the Table Mountain sandstone, presumably Silurian, and below this again a gap or uncomformity representing such a vast lapse of time that the rocks the Table Mountain sandstone lies upon can at the latest be only Cambrian, but are more probably Archæan. These rocks below the Table Mountain sandstone are included in the Pal-Afric group, which itself is made up of a series of formations, each separated by great unconformities, which cover a period probably equal in time to the whole period of deposition of sediments in Europe from Cambrian to the present day. As tabulated we have then—

Neo-Afric Group	Cape Formation	Bokkeveld Series Table Mountain Series	Devonian Silurian
	Unconformity.		
Pal-Afric Group	Waterberg Formation		Archæan ?
	Unconformity.		
	Transvaal Formation	Pretoria Series Dolomite Series Black Reef Series	
	Unconformity.		
	Witwatersrand Formation		
	Unconformity.		
	Swaziland Formation		

Below come gneisses, and below these granite.

All these rock-systems have unconformities between them, representing land periods during which vast quantities of material were carried away by rivers to the sea. Even after the commencement of more recognisable periods in the Neo-Afric era, Africa stood and has been standing above the sea for longer continuous periods than in any other known part of the world. In this way, I think, we can explain how it is that we in South Africa stand nearer to the earth's centrosphere than people in other parts of the globe.

There is other evidence of an entirely different character which bears out this conclusion in its entirety. If we regard the earth as more or less spherical and then compare the distribution of land and water, we shall find that Africa stands in the centre of the land masses, and on the other side of the

world lies the greatest expanse of ocean (see map, Fig. 31 p. 204). The globe is actually pear-shaped, as Jeans has expressed it; Africa stands, as it were, at the stalk end and the Pacific occupies the broad end.[1] This configuration can best be explained by the fact that the rind of the earth has been more pared away by denudation in Africa than elsewhere, and the diminished weight of crust has allowed the centrosphere to expand and bulge the area occupied by the African continent. As previously explained, Suess holds that the attraction of the continents on the water of the ocean diminishes the contrast in relief between continents and oceans, so that, could we remove the watery covering, the pear-shaped form of the earth would stand more clearly revealed.

Has earth movement, faulting, and thrusting anything to do with the eruption of this centrospheral magma? The work of Hall on the faulting and fissuring in the rocks north of the Johannesburg-Pretoria granite seems to answer the question in a categorical affirmative. It has always been recognised that the diamond mines run in linear series, often, as in the Kimberley group, in parallel series, and that the mines are never circular, but always have a tail directed along the fissure plane. Many mines, as, for instance, the Bultfontein, are actually double, and are connected with a dyke of blue ground which occupies the plane of fracture. But Hall's evidence is far more positive than this.

In the Pretoria district there is on the south a great boss of granite and to the north the Bushveld plutonic complex, consisting of much younger granite with a selvage of more basic rocks. This came up and folded the rocks between it and the old granite. Where the beds were nipped between the young and old granites the axes of the folding follow the line of the latter, but round the eastern margin of the old granite the folds splay out in precisely the same way as they do in the south of Cape Colony round the George granite. But instead of folds radiating diagonally to the general trend,

[1] J. H. Jeans, *Phil. Trans. Roy. Soc.* 1903, Ser. A, p. 157.

producing cross folding as in the latter case, in the Pretoria district there are a number of faults. One can illustrate this by taking a bar of soap and bending it; the axes of the folds would be represented by the long axis, now bent, of the bar, and across the bar there would be produced fractures similar in direction to those occurring in the rocks in the Pretoria district. On the continuation of one of these great faults lies the Premier diamond mine. It is true the fault cannot be recognised on the surface in the neighbourhood of the pipe, but faults die out towards the surface, and it is quite certain that the fault pointing straight towards the mine in the vicinity of the granite must be continued up to the mine below the surface.[1]

Is this, however, not merely a case in which the fracture has given relief to pressure and the molten magma has taken advantage of it? The question is difficult to answer from the point of view of the Premier mine alone. The blue ground of this pipe is one far more full of fragments torn from the sides of the chimney than is usually the case; indeed the edges are often more a crush-breccia with a little blue ground intermixed than actual igneous material. But there is no reason to suppose that therefore the chimney is an explosion vent only; rather I look at the tearing away of these fragments as having been caused by the swelling of the magma under the influence of hydration and the movement consequent upon it. Taken, however, in connection with the Drakensberg volcanoes, the evidence points to the cause of the upwelling of the magma to the fresh creation of molten rock by the earth movements, and not to its escape from imprisonment along an accommodating fissure.

The rarity of diamond mines elsewhere can be explained by the fact that fissuring seldom penetrates below the zone of siliceous rocks, granite, and so forth. That the same causes bring about similar effects with different material is abundantly

[1] A. L. Hall, "The Geological Survey of the North-Eastern Portions of the Pretoria District," *Rept. Geol. Survey*, Transvaal, 1904, Pretoria, 1905, p. 37, ; A. L. Hall and F. A. Steart, "On Folding and Faulting in the Dolomite," *ns. Geol. Soc. S. Africa*, vol. viii., Johannesburg, 1905, p. 7.

shown in the Swabian mountain land, where, as Branco has pointed out, there are 125 embryonic volcanoes of the Kimberley type,[1] without, however, any diamonds in them, the same in the Shetlands and the Firth of Forth as Geikie has shown.[2] Conversely the diamonds of India occur in a Cambrian conglomerate—that is to say, were brought originally from the central portion of the earth at a time when the siliceous crust was still but a thin one. How the Brazilian diamonds were brought to the surface no one knows, but Minas Geraes, the mining district where they are found, is an exceedingly old land with a thin covering of later sediments; the very slow rate of increase in the temperature, as one goes downwards there, is comparable to the slow increase in the mining districts of South Africa, and indicates that one is nearer there to the cold interior of the earth than elsewhere.

We have already noticed the theory that the diamond mines might have been holes drilled by the impact of huge meteorites from above, the resemblance of the blue ground in its original form being similar to that of many meteorites, and we stated that the common denominator, which undoubtedly exists, has hitherto not been found. The above explanation gives the clue, and serves as a justification for Farrington's surmise that the average composition of meteorites represented that of the earth as a whole. There is no doubt that the Kimberley blue ground has come up from below, for there are many actual dykes of the substance filling fissures between rocks in such a way that they cannot be explained as portions of a meteorite which have been squeezed out owing to earth movements; they have all the characteristics of normal igneous dykes.

It is noticeable that the farther we go away from the granite the poorer the pipes of blue ground become. In the east of the Orange River Colony there are several mines, such as the Monastery, in which the blue ground does not pay for

[1] W. Branco, *Schwabens 125 Vulkan-Embryonen*, Stuttgart, 1894.

[2] Sir A. Geikie, "Geology of Eastern Fife," *Mem. Geol. Survey, Scotland*, Glasgow, 1902.

working, whereas still farther away in Sutherland, in the centre of the Karroo, innumerable pipes occur with rock in them indistinguishable from blue ground, yet they are entirely barren as regards diamonds. In the east of the Orange River, the Karroo and Stormberg sediments, overlying the granite, are comparatively thin, while in Sutherland the Karroo rocks are some 10,000 feet thick. It appears, therefore, that the fault planes, which have produced the necessary heat to bring up the igneous material, were all more or less of equal vertical extent. At Kimberley and near Pretoria they started near the surface of the granite and dipped down well into the meteoric matter of the centrosphere; in the east of the Orange River Colony they started some three or four thousand feet above the granite, pierced this and tapped a little of the internal magma; but in Sutherland, starting some ten or fifteen thousand feet above the granite, they brought up molten material, but instead of this consisting of the true meteoric ultra-basic rock melted up, it was simply the Pal-Afric rocks and granite reduced by frictional heat to a molten state, yet, because of the same primary cause for the production of the pipe and its contents, the rock simulates in all essentials that of the Kimberley blue.

South African geologists are often accused of being obsessed with the theories concerning the diamond mines; but it is only when large pecuniary interests are centred in some geological phenomenon that there is possible that minute investigation and discussion which such problems require. The description of the deposit of iron ores would scarcely be possible had it not been for the American investigations maintained by the great iron industry, and the nature of faults would not have been understood so completely as they are had they not been worked out in connection with coal-mining in England and Belgium. The prominence I have given to the diamond mines is, therefore, not because they are givers of riches to South Africans and others, but because we know more about them than most volcanic groups.

The evidence of the melting of the rocks due to frictional heat along a fault plane, which was not clearly shown in the case of the Premier mine, is given in a very clear way in the volcanoes on Mimosa. Here we have a great fault letting down the cretaceous (Uitenhage beds) against the older rocks, as in the Baviaan's Kloof fold-basins. Instead of the older rocks being infusible quartzites, as in the latter case, the fault traverses Dwyka conglomerate, Witteberg beds, and Bokkeveld beds below that. The Dwyka conglomerate is a glacial

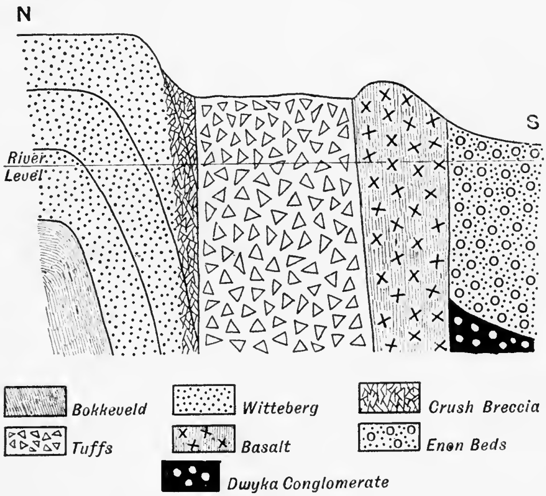

Fig. 29.

Section across the western volcanic neck on Mimosa, near Port Elizabeth, Cape Colony.

boulder clay of Permian age, which has as matrix a calcareous mud; the Witteberg beds consist of ferruginous thin-bedded quartzites, with intercalated ferruginous shales; the Bokkeveld beds consist of calcareous shales and occasional sandstones and limestones. All these rocks have low melting points compared with pure silica; the limestone forms a flux, which allows the fusion of the iron, and this, reacting as a flux on the aluminium silicates and quartz, renders the whole fusible at a much lower temperature than any of the substances are when taken separately. Consequently, instead of brecciation,

the friction has developed heat sufficient to melt the rock, and two little necks of lava and tuff with a long fissure dyke of basalt have resulted (Fig. 30).

The tuff is interesting as affording a clue to the depth to which the fissure penetrates; they are pink, green, cream-coloured, and brown, and vary in constituents, although small particles of volcanic glass are common to all. They are

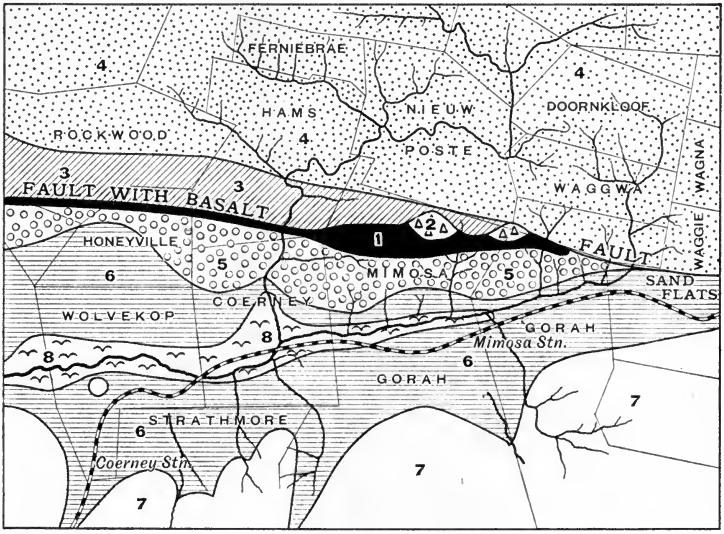

FIG. 30.

Geological sketch map of the Mimosa volcanoes, after A. W. Rogers. 1. Basalt. 2. Tuff. 3. Dwyka Beds. 4. Witteberg Beds. 5. Enon Conglomerate. 6. Wood Bed of the Uitenhage (Lower Cretaceous) System. 7. Alexandria Beds (Uppermost Cretaceous). 8. Alluvium.

described by Rogers, who records in the cream-coloured variety fragments of quartz, quartzites, and felspar in a matrix composed of chips of quartz, microcline, plagioclase, garnet, green hornblende, and zircon. The presence of microcline shows that the underlying granite has been tapped for the production of explosion products, but the basaltic lava points to the fact that it has had an origin above it in the calcareous slates of the Bokkeveld and ferruginous quartzites and slates of the Witteberg series. The presence

of two neighbouring fault lines, one in refractory rocks with brecciation, and the other in fusible rocks with melting, stands in such significant relation that it is impossible to escape the conclusion that the fusion is due to crustal friction. This is brought home to us especially when we remember that although the explosive action drilled a hole right down to the granite, the lava did not well up in the channel provided for it, which it must have done if there had been a reservoir of molten magma in the depths of the crust. On the contrary, the lava filled in the fissure and a little of the larger openings in the twin pipes, but left the greater portion of these occupied by the loose fragmental matter.

It is not my purpose here to treat the whole subject of the development of volcanoes from crush-breccias, through tuff-filled chimneys to normal ash and lava extruding volcanoes, I have already done so elsewhere;[1] but it is interesting in this connection to trace the gradual development of heat in the various examples of what Branco calls embryonic volcanoes. In Swabia, only in rare cases are the rocks included in the tuffs affected by heat, and the same has been observed in the gneiss and granite blocks in the tuff in the Weinfelder Maar in the Eifel, as described by von Dechen.[2] Sir A. Geikie, describing the rocks in the volcanic necks in the Firth of Forth, says: "In the vent at Elie Neck among the non-volcanic contents of the agglomerate, special reference may be made to the numerous fragments of crinoidal limestone in certain layers. These show no trace of metamorphism, their crowded organisms being as clearly recognisable as in pieces of limestone from a quarry."[3] In the Kimberley blue ground fossil fish have been found in blocks of sandstone quite unaltered. Then in the Schleuersbach volcano in Swabia, the marly middle Lias blocks, as well as the rocks in the circumference of the pipe,

[1] "The Rocks of Tristan da Cunha," *Trans. S.A. Phil. Soc.* vol. xvi., Cape Town, 1905, p. 27.

[2] *Geogn. Führer zu der Vulkanreihe der Vordereifel*, Bonn, 1861, p. 254.

[3] "Geology of Eastern Fife," *Mem. Geol. Survey, Scotland*, Glasgow, 1902, p. 241.

are burnt black, while the included belemnites are altered to white marble.[1]

From these examples of moderate heat we pass to ash thrown out from actual volcanoes, as, for instance, that which was ejected from Mount Pelée as an incandescent cloud, and caused the destruction of the town of St. Pierre in Martinique in 1902.[2] In Ascension there is a white earthy stone, forming isolated hills, which was thought by Ehrenberg to be an admixture of volcanic dust and diatoms, a pyrobiolith,[3] and Prestwich[4] supposed that these diatoms had lived in subterranean reservoirs of water which were pierced by the chimney of the volcano. From an examination of the *Challenger* material, however, Renard established that the organic particles were the siliceous stems of grasses,[5] and hence we may imagine that the dust was formed somewhat like that of the incandescent cloud of Mount Pelée and that in rolling down over grass-covered slopes it incorporated the stems of the grasses without entire fusion. In the Cave Sandstone, a non-volcanic tuff consisting of sandstone and granite débris, the grains of quartz are altered by having their borders crowded by little talc scales, due to the action of hot vapour, and, from the presence of these scales enveloping the grains, the rock has the appearance of chalk rather than that of a sandstone. From this stage we pass to actual fusion ; I have in my possession slides of tuffs from Kenhardt, Cape Colony, in which the grains of quartz and microcline are actually fused round the edges. From this stage the gradation to actual melting as in lava is easily conceivable.

Turning from the consideration of a single small fault with its puny volcanoes, let us take the larger zones of fracture in the earth's crust.

Fracture and folding are related in that the one is due to tension and the other to pressure ; both indicate a mobility of

[1] *Schwabens 125 Vulkan-Embryonen*, Stuttgart, 1898, p. 546.

[2] T. Anderson, *Volcanic Studies*, London, 1903.

[3] "Über eine bedeutenden Infusorien haltenden vulkanischen Aschen-Tuff auf der Insel Ascension," *Berichte d. k. Akad. d. Wiss.*, Berlin, 1845, p. 140.

[4] *Proc. Roy. Soc.* No. 246, 1886, p. 156.

[5] *Chemistry and Physics*, Pt. II. vol. vii. p. 42.

the crust along certain lines, and both are due primarily to the same causes, which are, weighting of the crust by prolonged sedimentation, and relief of pressure due to denudation. In the larger sense these zones, or lines of mobility, are known by Dana's term of Geo-synclinal, though Hall first pointed out the true cause of their existence. Alteration of load is most pronounced where there is greatest relief in the earth's surface; it mostly occurs along the shore lines of the continents, but great mountain ranges like the Himalayas and Alps, where denudation is very rapid, also give rise to lines of motion.

Mobility in the crust is shown by earthquakes, for when the strain comes upon it the tendency is to resist, and consequently a time comes when the strain becomes too great and the resistance is overcome. Motion, therefore, is not continuous, but acts by successive jerks which shake the whole surface of the globe.

According to Haug there are three great geo-synclines belonging to the recent geological history of the globe:—(1) The West Indian - Alpine - Mediterranean - Javanese line separating the North Atlantic from the Africano-Brazilian continents and the Chinese-Siberian from the Australian-Indian-Malagasy continents; (2) the Mozambique-Ural line crossing the last at right angles and dividing the hemisphere into two halves; and (3) the Circumpacific line surrounding the sunken area of the Pacific. These lines are also the zones of greatest seismicity as Montessus de Ballore has pointed out, and, in fact, if motion takes place along them, they would necessarily have to be the seat of the greatest earthquake activity. And they are also the zones of greatest vulcanism.

If we accept the conclusion that the earth's crust is equal in composition all over, and that, as continents have manifestly been often converted into ocean basins, the oceans conversely have often, during the geological history of the earth, been converted into continents, then these geo-synclinals are the outlines of great fault-pits such as the Baviaan's Kloof fold-basins. That is to say, there is one general type of action by

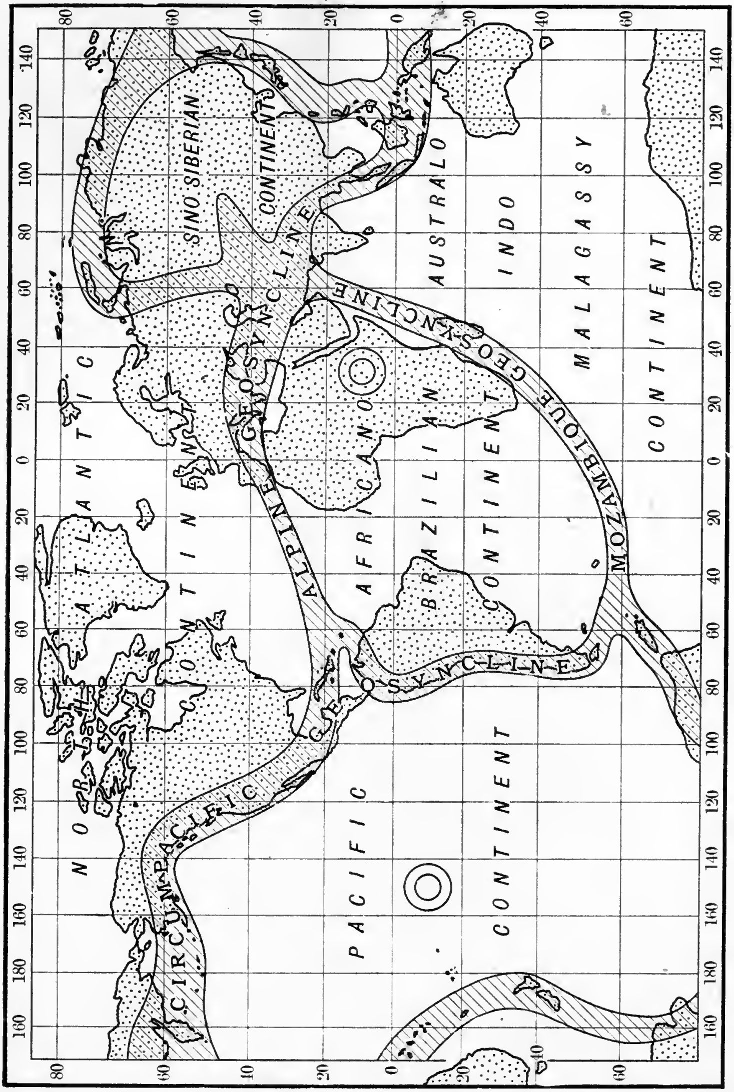

FIG. 31.

Map of the world showing Haug's geo-synclines and the continental areas now depressed wholly or in part. (*Bull. Soc. Geol. France*, 3rd ser. vol. xxviii. 1920, p. 617.) The circle on Africa shows the centre of the land masses of the globe, the stalk end of the pear of Jeans' conception of the earth; the antipodal point in the Pacific is the centre of the maximum oceanic area, occupying the broad end of the pear. See p. 195.

which segments of the earth are let down, which finds its most minute illustration in the Steinheim basin and its largest expression in the submergence of continents to form ocean-basins, and according to the depth to which the earth movements penetrate, so the resultant phenomena round the edge of the displacement are crushing or melting.

In the world-segments which let down ocean-basins, the sinking can be traced directly to the additional load of

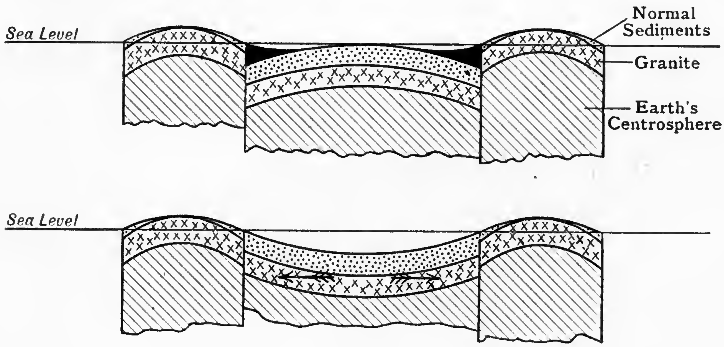

FIG. 32.

In the upper diagram the distortion of the earth's crust under the ocean-floor by weighting of sediments is shown; in the lower diagram the earthquake waves passing in both directions through the lower rocks of the sea-floor have heaped up the crust against the continenta blocks which are made of materials more opaque to earthquake waves. The interaction of the two motions keeps the ocean-floor more or less level, but causes pressure to accumulate along the shores of the continents.

the sediments deposited upon the periphery; but this will not account for the whole area of the ocean sinking. There has hitherto been a lacuna in the argument in this respect. Continents are tilted and lifted upwards by the lessening load due to the wasting and carrying away of the rocks which make up their surface, and the shore line within 200 miles of their coast would sink by the deposit of this land detritus. If this were the only cause for the sinking of ocean basins, then these should be narrow belts of deep water separating continents that could not be more than some 400 or at most 600 miles apart. If, however, we regard continents as bulges of the crystalline siliceous crust, and that such bulges are due to the removal of the looser sediments from the top, then earthquake

shocks, resulting from whatever cause that can produce them, would continually break against the buffer of ancient crystallised sediments. There would be two areas, in one of which, as we shall see in the following chapter, the shocks are transmitted rapidly, that is to say, the sediments of the ocean floor, and one in which the vibrations are damped down in the ratio of 5 to 3 or 3 to 2, that is, in the granite substructure of the continents (Fig. 32). What would happen in such a case is that the earth material would tend to be heaped up along the shores by the continual shaking of the earth. But it is in precisely these places that the sedimentation is most rapid, and the extra loading depresses the earth's crust. The net result is that the surface of the ocean near the shore is not raised as much as it should be by the breaking of the earthquake waves on the continental blocks, nor is it depressed as much as it should be by the weighting of sediments. But with vertical movements going on under pressure, the heat developed by the friction of the two segments, the continental block and ocean floor, is so great that melting goes on and volcanoes result along the line of movement. The Pacific circle of volcanoes is the most splendid example of this.

Under similar circumstances the downward movement along the border of continents progressing under pressure may give rise to folded mountain ranges, as shown by Mellard Reade and Suess, and the pressure would then come directly from the direction of the sea. That this is not always so is shown in the folded mountains that border the southern coast of Cape Colony; there the pressure undoubtedly came from the interior. In this case, however, two continents, between which the sediments of the Neo-Afric series were developed, were little more than 400 miles apart, the one running with a shore line about north-east through the Southern Transvaal, and the other being a prolongation of the Madagascar ridge southwestwards; hence there could not arise that compression from the sea which obtains from shores facing the open ocean. The actual pressure and sinking zone along the south and east of Africa lies outside the Madagascar ridge.

On this theory we regard folding of mountains and volcanoes as different manifestations of the same cause, compressive movement in the earth's crust. To understand this point of view we have to define our conception of earthquakes and then that of the crystalline substructure of the normal sediments.

CHAPTER XV

EARTHQUAKES

It is not intended here to review the science of Seismology, nor to treat of the earthquakes as recorded either by the destruction of towns or by instruments specially designed for the purpose. It will suffice to establish that earthquakes large enough to be felt are continually shaking the earth, and that if we make our instruments delicate enough they show that the earth is continually quaking.

If a heavy weight be dropped on to the soil or on to sand, the shock will be felt at a certain distance and the speed of transmission can be observed ; it is found to be a few hundred feet a second. In granite deeply buried in the earth the rate would be many thousands of feet a second. That practically is the net result of earthquake investigations with which we are concerned here—the absorption of energy by the rocks near the surface of the earth owing to earthquake movement.

There are two sets of vibrations set up when the earth is shaken by a blow, either by the impact of a falling weight or by a volcanic explosion, and the same holds good for the more common kind of earthquake, that produced by the snapping of rock along a line of fracture. These two kinds are called the normal or compressional vibration, which is of the same nature as the vibration which travels through a liquid, and the transverse vibration, which is a distortional vibration and can only be propagated in a solid. The investigation into the way in which rocks respond to these vibrations, and the rates by which they transmit them, cannot be reduced to any law, as in the case of homogeneous substances such as steel or glass. Prof. Nagaoka, who

conducted a long series of experiments in this connection, found that when any large amount of loading or twisting was applied to rocks they nearly all failed to return to their original shape, that is to say, there was permanent distortion. In bedded and jointed rocks, also, there was an additional disturbing factor, for the rates perpendicular and parallel to the bedding was markedly different. The following table shows a few of the results obtained by Nagaoka. z is the density, e_1 the modulus of elasticity perpendicular to the bedding, e_2 parallel to the bedding, E the mean, M the modulus of rigidity (torsion), V_1 the speed of the normal wave, V_2 that of the transverse wave in kilometres per second.

TABLE OF ELASTIC CONSTANTS OF ROCKS AND WAVE SPEEDS IN KILOMETRES A SECOND (NAGAOKA)[1]

	z	e_1	e_2	E	M	V_1	V_2
Archæan—							
Chlorite Schist .	2.955	146.0	147.6	146.8	31.57	7.05	3.27
Palæozoic—							
Clay Slate max. .	2.149	79.69	83.29	81.49	28.06	6.16	3.61
Do. min. .	2.384	34.48	30.76	32.62	8.00	3.70	1.83
Limestone . .	2.630	84.95	88.45	86.20	29.83	5.74	3.38
Mesozoic—							
Clay Slate max. .	2.702	83.6	85.3	84.5	18.5	5.59	3.17
Do. min. .	2.678	43.7	44.3	44.0	14.2	4.06	2.31
Sandstone . .	2.216	9.2	9.0	9.12	3.1	2.03	1.18
Granite max. .	2.572	37.91	46.71	42.31	18.43	4.05	2.68
Do. min. .	2.530	11.97	9.89	10.93	4.43	2.08	1.32

Taking the averages, we find from the tables :—

	No. of Specimens.	Rate of Normal Vibration.	Of Transverse Vibration.
Argillaceous and Calcareous rocks .	27	5.12	2.72
Sandstone	4	1.96	1.18
Granite	6	2.84	1.81

[1] H. Nagaoka, *Publications of the Earthquake Investigation Committee in Foreign Languages*, No. 4, Tokio, 1900; *Phil. Mag.* ser. v. vol. i. 1900; reprinted in C. E. Dutton's *Earthquakes*, London, 1904, p. 230.

It is, of course, unwise to generalise on a few laboratory experiments, but allowing for all the vagaries in the results from the 67 rocks tested, the fact remains clearly expressed in them that waves are transmitted at a slower rate in granite than in normal sediments. If we take the rates of sands to clays as equal, then the ratio of the rates will be 3.52 to 2.84 and 1.85 to 1.81; but remembering that the sandstones form only a fringe round the shores while the argillaceous rocks and limestones have enormously greater distribution, the working ratio in nature will be nearer, for the normal wave, 5 to 3, and for the transverse wave, 3 to 2. These would express the relative vibratibility of the rocks of the sea-floor to the continental blocks.

The matter can be thought out from the nature of the rocks, although it is better always to have experimental proof. In a clay-rock or limestone the substance is more or less homogeneous, whereas in a granite there are grains of quartz, felspar, and hornblende or mica, lying in all directions, with no relation of their axes of elasticity to the bulk or to one another, each with different moduli of rigidity and elasticity, and quite irregular in shape, while the grains are separated by sharp margins which reflect waves, and also to some extent enable each grain to move independently of the others. Such a medium, therefore, is bound to damp out vibrations. The same considerations explain the low rates of vibration in sandstone where the grains are similarly separated.

In nature rocks would be under more favourable conditions for transmitting vibrations owing to the pressure and water held up in the capillary and sub-capillary interspaces, and also owing to the wide extent of the different beds. In a bar of steel, for instance, the velocity of transmission of a plane wave is 5.3 kilometres a second, whereas in an unlimited medium it is 6.2 kilometres a second, or a ratio of .855 to 1. Whether the rates should be increased in this proportion is doubtful. The law that the velocity of transmission varies proportionally to the square root of the elasticity and inversely to the square root of the density of the medium, fails entirely

in rocks under large stresses and strains, so that it is impossible to apply laboratory results to the calculation of actual speeds of vibration in rocks. What does hold good, however, is the proportionate ratios of the vibration rates in the different media.

Besides velocity there are other elements to be taken into consideration in an earthquake wave. The energy of the quake is proportional to the square of the velocity. The velocity in turn varies directly as the amplitude and inversely as the period or time the earth particle takes to come back to the original position.

The amplitude of 20 millimetres in an earthquake is sufficient to destroy a town, 10 millimetres is a bad earthquake. One of half a millimetre is quite perceptible. The famous earthquake recorded by Humboldt when the town of Riobamba was overthrown in 1797, is said to have had an amplitude sufficient to throw the inhabitants on to the top of a hill several hundred feet high and on the other side of the river Lican; though this is stated in perfect good faith, it is impossible from the fact that only the inhabitants were found to have been so hurled into the air; the houses were thrown down, but the stones did not travel upwards along with the people. Amplitudes of 5 or 6 centimetres (2 to 2½ inches) have been noticed in a number of great earthquakes, but then these have long periods lasting over 1.5 and up to 2.5 seconds, so that although enormous destruction may be done, the rate of these great waves is too slow to hurl things into the air.

The following figures are given by Milne for the amplitudes of great earthquakes in Mexico, Alaska, Ceram, and Smyrna. In the table the amplitudes are given in millimetres, and below are the distances from the origin in degrees of arc of a great circle. Where > is placed before the number it indicates that the shock was greater than the instrument could record, and the figure given is the limit of amplitude recordable.

Catalogue No.	Origin.	Amplitudes above, distance in degrees of arc below.						
250	Mexico	>17	8	6	6	4.5		
		30	34	34	80	80		
344	Alaska	>17	2.5	5	·5	·75		
		20	50	70	105	145		
337	Alaska	20	4	5	3	2		
		40	49	77	105	165		
338	Alaska	>17	>17	20	9	4	10	
		40	70	77	105	145	165	
347	Ceram	10	5	1	1.5	2	·5	2.5
		22	47	62	73	105	105	121
343	Smyrna	9	4	1	6	4		
		25	43	65	74	85		

Generally speaking, the larger the initial amplitude the more rapid is the rate of decrease with travel. Thus in No. 337, between 70° and 105° the amplitude falls from 5 mm. or at a rate of .07 millimetres per degree, whilst from 105° to 165° the rate of decrease is .01 mm. per degree.

For period we can turn to Prof. Omori's tables of long distance earthquakes. In these are first set down the preliminary tremors, the vibrations which come straight through the earth by the "brachystochronic" paths, the first phase being the normal wave and the second the transverse or distortional wave;[1] the principal portion of the earthquake shock; and the end portion of echoes and reflected vibrations.

MEAN VALUES OF THE VARIOUS PERIODS IN THE SUCCESSIVE PHASES OF LONG DISTANCE EARTHQUAKES (OMORI)[2]

Preliminary Tremors.		Principal Portion.			End Portion.
1st Phase.	2nd Phase.	Initial Phase.	Slow Phase.	Quick Phase.	
Secs.	Secs.	Secs.	Secs.	Secs.	Secs.
4.6	5.1	3.3	4.1	5.7	4.8
8.7	8.5	8.4	8.6	9.3	9.6
20.8	20.3	22.9	22.3		2.2
	43.3	45.4			

[1] R. D. Oldham, *Phil. Trans. Roy. Soc.* ser. A. vol. cxciv. 1900, p. 135.
[2] *Publication of the Earthquake Committee in Foreign Languages*, No. 11, Tokio, 1902.

As a general rule waves of quick period are soon dissipated, and are not of sufficient power to affect far distant instruments because of their absorption on the way. Periods are in most cases longer as the distance from the origin increases, although one and the same quake may have many periods for different portions of the whole vibration.

Combining these factors, velocity, amplitude, and period, there are two points which stand out very clearly: firstly, that the earthquakes are transmitted in different ways in different portions of the earth's crust; and, secondly, that energy is lost on the way. To give some idea of this energy Milne gives the following example:—

In the Charlestown earthquake of 1886, assuming a displacement of 1 inch, a period of two seconds and a velocity of 3 miles per second, then the energy of a cubic mile of that earthquake near the epicentre would be twenty-four thousand million foot pounds. To disturb an area 100 miles square would require an energy of twenty-four billion foot pounds, expended at the rate of 1.3 billion horse-power.[1]

This energy is continually being communicated to the rocks, and becomes absorbed by them by friction, or by distortional movements. Although Nagaoka's figures are not arrived at from the study of rocks in their natural position, it appears that granite is definitely more dense to earthquake transmission than normal sediments; quakes coming from the sea do actually drag at the shores of the continents like a wave in the water, and that therefore the sediments near the shore must have a motion, not only of vibration, but also of translation communicated to them.

Oldham[2] has arrived at a somewhat similar result from an entirely different point of view, in considering the rates of transmission of the San Francisco earthquake of April 15, 1906, and that of Columbia on January 31, of the same year. As recorded in Europe, the intervals between the first and

[1] J. Milne, *Seismology*, London, 1898, p. 142.

[2] R. D. Oldham, "Origin of the Oceans," *Quart. Journ. Geol. Soc.* vol. lxiii. 1907, p. 344.

second phases of the earthquake were distinctly greater in the case of the Columbian earthquake, that is to say, where the quake traversed a larger segment of sub-oceanic crust. The rate of transmission of the second phase was slower. In other words, the continental mass of America, through which the quake passed, was more dense to the shock and therefore transmitted the two phases more equally, whereas in the sub-oceanic crust the material was less dense and energy was absorbed by it. According to Omori, the mean interval between the two phases of the earthquakes coming through the earth from the Pacific side was 9.7 minutes for a mean distance of 75° ; the interval deduced from the average curves based on continental wave paths only is 9.0. So here, again, we find that the material under the Pacific Ocean transmits the second phase waves at a slower rate, as compared with the first phase waves, than does the material under the Eurasian Continent. Oldham, however, considers the difference to be in the brachistochronic paths, which in the case of an arc of 75° gives a maximum depth of the straight path or chord, of .21 of the radius, and hence he concludes that the differences between the substance of continents and oceans extends to about one-quarter of the radius of the globe. But as we saw that the difference between the rates of the transmission of normal and transverse waves in granite was 1.03, and in sediments, leaving out sandstones, 2.40, it may be that the differences observed can be explained on the assumption that the waves in the one case are transmitted through a continent stripped of its sediments, and therefore consisting predominantly of granite, and in the other case they are transmitted under the ocean floor covered with sediments, rather than that there are profound differences of composition of the earth extending down to one-quarter of the radius of the globe.

It has been usual to consider that deeper in the earth's crust there are no differences between continent and ocean floor. Earthquake waves of long distance travel with approximately equal velocities of about 3 kilometres per

degree of arc throughout the various regions of the globe ; the crust, as a whole, heaves like an ice-floe upon the ocean, and, except for the outermost shell of the uncrystallised sediments, the whole is of one texture and of one composition.[1]

The greatest help which earthquakes afford us under the hypothesis we are discussing, is the evidence they afford that this crust is of similar composition down to 30 miles, below which there is a sharp alteration in the texture and composition of the globe. In a long distance earthquake there are what are called preliminary tremors, which are not transmitted through the heaving crust, but are sent along the shortest possible route, the brachystochronic path of Oldham ; if the earthquake is at the antipodes of the recording station, then these come through the whole diameter of the globe and arrive sooner than the main quake. The following table shows the interval between these two phases of the quakes :—

Intervals between Arrivals of Preliminary and Long Waves (Dutton)[2]

Degrees of Arc.	Time Intervals in Minutes.
20	5
40	11
60	20
80	29
100	38

The rate of transmission is 10 kilometres a second, nearly twice that in steel. If, however, the recording station is less than 1000 miles away these quick rates of transmission are not recorded. For direct paths between the shock and the recording stations, which do not penetrate below 30 miles in the earth's crust, the speed of transmission is such as is found in waves of compression in ordinary rocky material. The farther the chord or direct path penetrates this rigid, elastic centrosphere below the 30-miles crust, the more the wave is accelerated. Accordingly 30 miles is a maximum

[1] J. Milne, "Recent Advances in Seismology," Bakerian Lecture, 1906, *Proc. Roy. Soc.* Ser. A. vol. lxxvii. 1906, p. 369.
[2] C. E. Dutton, *Earthquakes*, London, 1904, p. 218.

depth at which we should look for materials having similar physical properties to those we see on the earth's surface. Beneath this limit the materials of the outer part of the planet rapidly merge into a fairly homogeneous nucleus with a high rigidity. Oldham has shown reason to infer that this also is composed of two portions—an inner core four-tenths of the radius of the globe, of very high rigidity, and an outer shell six-tenths of the radius of the globe, of less relative rigidity; but the proportions of these are much more nearly equal than the proportions between the whole centrosphere and the thin film of siliceous rocks of the crust.[1]

The main vibration of an earthquake is regarded as a distortional wave which has an average velocity of 6 kilometres a second; and it is the rates of transmission of the compressional or normal and the distortional or transverse wave which will enable us eventually to arrive at an understanding of the physical condition of our globe below the zone of direct observation.

[1] "From the considerations detailed, I conclude that the interior of the earth, after the outermost crust of heterogeneous rock is passed, consists of a uniform material, capable of transmitting wave-motion of two different types at different rates of propagation; that this material undergoes no material change in physical character to a depth of about six-tenths of the radius, such change as takes place being gradual and probably accounted for sufficiently by the increase of pressure; and that the central four-tenths of the radius are occupied by matter possessing radically different physical properties, inasmuch as the rate of propagation of the first phase is but slightly reduced, while the second-phase waves are either not transmitted at all, or, more probably, transmitted at about half the rate which prevails in the outer shell. If these waves are to be explained as those of condensation and distortion, then the rates between the modulus of rigidity and the bulk modulus is only two-thirds of that obtaining in the outer shell; but whether this interpretation be adopted, or some other, we still have a central core, the behaviour of which, with regard to these waves, differs materially from that of the outer shell." R. D. Oldham, "The Constitution of the Interior of the Earth as revealed by Earthquakes," *Quart. Journ. Geol. Soc.* vol. lxii. 1906, p. 471.

THE HEADS, KNYSNA

There is a narrow ridge of Table Mountain Sandstone between the sea and the fold-basin in which the town of Knysna lies; it is here shown breached by the estuary.

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CHAPTER XVI

THE ARCHÆAN ROCKS

WE know so much about rocks at the present day, and are so overwhelmed with detail, that we often lose sight of the great distinctions that underlie our classifications. Werner, looking upon geology from the point of view of a beginner, saw more clearly these differences and expressed them in his classification.

A. G. WERNER'S GROUPS	PRESENT GROUPS
Aufgeschwemmtesgebirge	Tertiary and Quaternary rocks
Flötzgebirge	Secondary
Übergangsgebirge	Palæozoic
Urgebirge	Archæan

Werner's terms indicate the remarkable stages in the rocks of the earth crust; first of all the Urgebirge, the primitive rocks, then the transition rocks followed by the normal sediments, and, finally, the loose deposit hardly compacted into rock. The Archæan or Urgebirge in Europe consists essentially of phyllite, mica-schist, and gneiss. In phyllite the slates have begun to be recrystallised and mica flakes are forming normal to the direction of pressure; in mica-schist the rock is wholly recrystallised, and in gneiss, new minerals, principally felspar, have come in in solution from outside, and have converted the rock into something nearer the average composition of the siliceous crust of the earth. In South Africa and North America especially these alterations have not gone on in the upper Archæan; the sediments are still recognisable as slates, quartzites, and limestones, but at the bottom, below them, is always the gneiss representing an earlier stage of the Archæan.

The production of gneiss from sediments is a fact which can be open to no doubt. In Bergen, in Norway, Reusch has found in the schists and gneisses trilobites and grapholites that are elsewhere found in normal Silurian slates. In Switzerland Jurassic belemnites are found in it and in California Cretaceous fossils. We have already discussed the mode of formation of gneisses in dealing with the work of underground water; stated in the shortest way, under pressure, rocks become dissolved by solvent water, the various types, sandstones, shales, and limestones, interchange substances, and the whole becomes crystallised in a more compact form.

The gap between the older sediments, Cambrian and Silurian, and the Archæan is an enormous one. We have seen in South Africa what a vast amount of denudation has gone on between the separate members of the Archæan. In Europe the Cambrian sediments often contain basal conglomerates formed of gneiss, showing that the sediments from which the gneiss was formed were buried deeply in the earth's crust sufficiently for dynamometamorphism to act, then they were removed by denudation, and finally covered with much later sediments of the Cambrian period. If we are to learn anything from these facts, which are exceedingly difficult to appreciate, as Archæan stratigraphy is one of the most controversial subjects in geology, then we must acknowledge that the changes from land to water were not so rapid in Archæan times as they became in later times.

A continuous deposit beneath the sea till the bottom beds are converted into gneiss, then a continuous land period till the gneiss is exposed by denudation, is a gap of almost unthinkable duration if we take our conceptions of unconformities from the Palæozoic or Mesozoic strata. In the latter the one system rests on the denuded surface of the one below with scarcely any difference in metamorphism between them, sandstone rests on sandstone, slate on slate, limestone on limestone; even when Tertiary rocks rest on Palæozoic rocks the alteration is nothing like so profound

as the difference between the base of the Cambrian and the Archæan. That there were sediments overlying the gneisses of the Archæan, which have been removed, is indicated even in Europe where occasionally a remnant of them is preserved, as in the Torridon Sandstone of the north-west Highlands of Scotland.

Taking the Archæan rocks as a whole, the land and water periods were of vastly greater duration than in the Palæozoic era, and Palæozoic unconformities indicate a longer lapse of time than in the Mesozoic. This becomes still more apparent if we compare the gaps between the Mesozoic and the Cainozoic strata, the last being of very short duration geologically speaking.

The same fact is shown in the rapid alternation of the varieties of sediments from shale to sandstone, sandstone to limestone, and so on, which we find in the more recent beds, whereas in the older beds, one series of slates, sandstones, or limestones will continue for hundreds or thousands of feet without change of character.

We cannot have recourse to the assumption that there was less water to do the work and therefore the time periods were longer. It is by the work of the agencies of denudation which are principally active through the medium of water, that we measure these time periods, and all the facts that we can learn from a consideration of the Archæan rocks point, if anything, to a larger amount of free water on the globe in Archæan times, and certainly to more active denudation than at present. Does our theory of a solid globe help us in this dilemma?

We regard the rocks of the earth's crust, divided into granite below, crystalline schists in the middle, and normal sediments on top, to be the original basic silicates of the meteorites in which the iron and magnesium have been leached out and have been drawn into the earth's interior, leaving only the siliceous materials behind. In the early stages of the earth's history the bombardment of bolides was too rapid, and the consequent heat too great, for any water

to settle if it were present, while the continual arrival of new material with unoxygenated gases kept the free hydrogen from combining with oxygen to form water. It was only in the very late stages of the astral period that water formed in any quantity on the earth. Consequently the amount of sediment deposited along the shores of the continents was at first very scanty, and from what we have been able to learn from working out the conditions then existing, the larger portion of rock waste carried away by rivers in those times was either in solution or in the form of argillaceous material : there were no deposits of sand and conglomerates, such as form near our shores at the present time and emphasise the load at the very borders of the land masses. It was only after these processes had gone on for a very long period that gradually the siliceous rocks became available for denudation, and sandstones composed of chert splinters and grains were laid down. So we trace the order of development of sediments from a condition in which chemical deposition, irrespective of shore lines, predominated, up to that in which deposition of mechanical deposits, closely hugging the shores, became the dominant feature as at the present day.

If, then, the primary motive power which produces earthquakes, folds the rocks, and causes faults and volcanoes, is the accumulation of sediments along the shores, with the consequent sinking of those portions of the crust under the additional load and the rising of the temperature curves within the crust, then the movements in the earth's crust must have been always a measure of the amount of normal sediments converted into rocks and forming the earth's crust. When these were slowly accumulated in the early periods of the geological history of the globe the movements were very slight, and the oscillation period of continent and ocean floor was a very slow one ; as the siliceous crust increased in thickness the oscillations became more rapid, until, as at the present day, they are noticeable even in historical periods.

The dilemma with which geologists are faced in the Archæan unconformities, when regarding the earth's crust as a

siliceous slag resting on a molten interior, not only disappears, but the very difficulties become additional and strong supporters of the theory of a globe built up of solid meteoric material.

The question arises: Are we to include the granite with the Archæan gneisses? Working on an Archæan area like that in the north-west of Cape Colony, the difference between the two is unrecognisable. In the area shown on the map (p. 24) the rock marked granite is principally gneiss, with a foliation parallel to the great lines of strike of the mountains composed of Keis quartzite and Griquatown beds. But in the centre the foliation planes are hardly recognisable, and from the midst of the area there arise bosses of granite and felsite which lie across the planes of foliation; these are taken usually to be intrusions of igneous granite in metamorphic granite, but the distinction is one without a difference.

Consider what happens in a slate when pressure comes upon it. The original shale from which it is formed may be bedded and folded in many ways. When the pressure is brought to bear the slate flows and squeezes out normal to the pressure, and with no possible relation to the bedding; if the latter coincided with the plane of flow, then bedding and cleavage will be the same, but if the bedding is inclined or at right angles to the flow, then the bedding will show across the cleavage. In slate the particles of kaolin are simply drawn into parallel position like the starch grains in dough which is rolled, but if the rocks are sufficiently compressed and for a sufficient time, the percolating water will recrystallise the rock, forming a schist, with the mica flakes crystallised normal to the pressure. Finally, under intense pressure new minerals will come in and form crystal aggregates still parallel to the old lines, that is, normal to the pressure; so a banded gneiss is produced. If now the rocks undergoing dynamometamorphism are so deeply buried that the conditions of recrystallisation are intensified, the rock will be reduced to the condition, not of a solid, but of a liquid. The difference between a solid and a liquid is the possession of the property

to resist deformation in the former which is absent in the latter. A rock, then, under immense pressure in the earth's crust and containing solvent water will be a mass practically liquid, which will transmit pressure equally in all directions. Hence the conditions necessary for the production of foliation planes are absent, but recrystallisation goes on as before, and as we know gneiss forms from sediments and contains all the minerals of a granite, so with a little more pressure, if the rock is a little deeper in the earth's crust, the sediments must produce a granite without any trace of foliation.

The presence of graphite in gneiss, in granite in the Ilmen Mountains, in syenite, foyaite, and other igneous rocks, is again an argument that these are not primordial rocks, but are metamorphosed sediments.

The presence of solvent water is the all-important agent without which the rock cannot be transformed into a potential liquid. This is the flaw on which all theories as to the liquid interior of the globe come to grief. Physicists know that rocks have been melted by pressure and heat in the earth's crust, hence they infer that pressure will reduce all rocks to a liquid and even gaseous state. They know that metals under pressure will flow, such as lead, but steel has never been made to flow except with the addition of heat. We have seen from Prof. Nagaoka's experiments that rocks do not respond to pressure and torsion as homogenous substances, but experiments have not been conducted with sufficient range of pressure to indicate what will happen if a rock is crushed dry and cold under vast pressures such as obtain in the earth's crust.

If the earth's interior retains any of the residual heat of its formation, then the crust would have to be very thin, owing to the great relative amount of radium known to exist in rocks of the earth's crust. But we know from the way that earthquake waves are transmitted that the earth's crust is 30 miles thick. Hence the earth's interior must be cold, and how rocks respond to dry pressure, no matter how vast it may be, is a subject about which we know nothing. Our reasoning in this book necessitates that under mass static

conditions, the compression should fail to break down the architecture of the molecule, and the rock should remain a solid even at the centre of the earth.

We can get at this result in a roundabout way. In the earth's crust we have an outside layer of known opacity to earthquake waves; this belt extends from the surface down to 30 miles, and the rocks must be in the same physical condition at the bottom as they are, say, a mile down. In other words, rocks at 30 miles depth must have at least sub-capillary interspaces filled with water, and must therefore be in the condition of a solid. The pressure at 30 miles is 13,000 atmospheres, or a pressure of 195,000 lbs. to the square inch, and if that is not sufficient to alter the state of the rock, it is futile to reason from laboratory experiments which have not such pressures available. Below the 30 miles there is a mass twice as rigid as steel and quite distinct in properties to the rocks of the crust; we can best obtain a conception of this by assuming that there are no sub-capillary interspaces below this point, and hence water cannot exist there.

The junction, then, of the Archæan granite and the centrosphere will be that of a potential liquid resting on a solid. The magnesian silicates of which the centrosphere is composed would liquefy if water could penetrate to them. Let us follow what happens to them when the water, drawn from the earth's surface by capillary and molecular attraction through the Archæan rocks, reaches them.

The bulk of the magnesian silicates, forming roughly four-tenths of the solid nucleus of the earth, were included in the earth when the atmosphere was devoid of water or free oxygen. It is the surface, then, of the great sphere with which we have to deal. It is quite possible that sub-capillary interspaces may still persist even in rocks below 30 miles from the earth's surface, and hence water may still be drawn into the surface of the meteoric material. The existence of pipes of this type of rock in the Kimberley mines is an argument in favour of it. But what would happen in this case? The rocks would become hydrated, that is to say, the water

would become chemically combined with the silicates and, as a result, the rocks would swell. The following table taken from Van Hise will show the amount of increase according to the nature of the gases included in the water and the composition of the olivine :—

Chemical Reaction.	Alteration of Olivine to	Volume increase per cent.
$3Mg_3FeSi_2O_8 + 6H_2O + O = 3H_4Mg_3Si_2O_9 + Fe_3O_4$	Serpentine and magnetite	29.96
$3Mg_3FeSi_2O_8 + 4H_2O + O + 3CO_2 = 2H_4Mg_3Si_2O_9 + Fe_3O_4 + 3MgCO_3 + 2SiO_2$	Serpentine, magnetite, magnesite, and quartz	37.13
$3Mg_2Fe_2Si_2O_8 + 4H_2O + 2O = 2H4Mg_3Si_2O_9 + 2Fe_3O_4 + 2SiO_2$	Serpentine, magnetite, and quartz	12.43

or taking the various possible silicates we have the following increases, the original mineral being recognised as unity.

TABLE SHOWING INCREASE IN VOLUME OF BASIC SILICATES OWING TO HYDRATION

Albite	$Na_2Al_2Si_6O_{16}$	increase to	1.2082
Anorthite	$CaAl_2Si_2O_8$	,,	1.3465
Diopside	$CaMgFeSi_3O_9$	,,	1.2788
Hypersthene . . .	$MgFeSi_2O_6$	,,	1.1284
Olivine	$Mg_2Fe_2Si_2O_8$	,,	1.1519

Any sub-capillary spaces, then, would apparently be obliterated by the incorporation of the water in the substance of the silicate, which would consequently swell and occupy the vacant space. The hydration of the centrosphere would therefore not proceed. If some such action did not take place all the water of the surface would be drawn down to hydrate the centrosphere, and in course of time the earth's surface would be depleted of its watery envelope. In the reactions quoted it is supposed that either carbon dioxide or oxygen is present in the water; that is not likely to be the case under great pressures, both because the rocks above have taken toll of these gases for their own purposes, and also because the pressure would exceed that by which the gas is

held in the water. Besides, the reactions necessitate the presence of water as water, whereas at this depth the water is probably dissociated into the constituent oxygen and hydrogen. I say probably, in deference to expressed opinion, but since we find that even within the small scratchings of the earth's surface which man has had the power to make in the deep mines, at 5000 feet, in the Archæan rocks, the approach to the cold interior of the earth has reduced the average temperature gradient of 1° F. for every 60 feet, to 1° F. for every 200 feet, hence it is not impossible that this decrease goes on down to, say, ten or fifteen miles. At this depth the influence of the interior of the earth at absolute zero (but for what heat it receives from the crust) would make itself felt in an actual reversion. It is legitimate therefore to assume that from 1° F. for 200 feet we should go below, say, the second mile to 1° F. for 800 feet, below the third mile 1° F. for 3200 and then beyond a decrease in temperature on the same scale to absolute zero, below the crust. As a result, water would be able to exist as water at the bottom of the crust, as indeed earthquake researches seem to indicate.

The intrusion of great masses of granite into the older rocks of the earth's crust, and indeed into younger ones, does not in any way interfere with the theory of the solid globe. The paring away of later sediments from the surface of a segment of the earth's crust during continental conditions brings the surface nearer to the rocks under potential liquid conditions. The presence of a zone deep within the crust where the temperatures decrease as one goes downwards would immensely simplify our argument, for then with the removal of sediment from on top, colder rock from deep down would be brought into the zone of higher temperatures, expansion would result, and thrusting of the molten material upwards would follow. That, however, is bringing in factors about which we at present know nothing. The intrusion of granite masses can be explained more in accordance with known facts if we imagine them as the result of pressure

zones in the earth's crust. With the pressure acting under mass dynamical conditions, that is to say, if there was differential movement in the earth's crust, the pressure and frictional heat would cause the potential melting of this zone to be translated into actual melting. The heat energy of the mass, liquidity, or whatever phrase we like to give to this condition, was increased, there was a surplus over for the melting of the surrounding rocks ; the side walls of the newly formed liquid mass became fused with the magma, as was also the roof, so the liquid material won its way upwards. When all the energy was dissipated then the whole cooled and crystallised as a great dome of granite in the earth.

Slow rising of liquid of this kind is familiar to geologists in the case of laccolites. There are magnificent examples along the southern flank of the Drakensberg. The strata of Karroo shale abut abruptly against the domes of basic crystalline rock, and the space occupied by the latter has been clearly melted out by the igneous rock itself. In the Henry Mountains in western North America there has been hydrostatic pressure, and the molten rock has lifted a dome of sediments above the laccolite, but such can only occur when the rocks are easily adaptable to bending, on account of a large amount of included water. That granite often plays the same part is shown in the usual areole of metamorphosed sediments with foliation planes concentric to the intruding boss.

It is hard to understand the line of great bosses of granite on any other theory. Take the string of carboniferous granite bosses in Cornwall and Devon for instance. Had these been intruded because fissures penetrated to the molten interior of the earth surely they should have occupied a continuous line. But if they are due to melting along pressure zones, then we can parallel them with crush-breccias along faults, which occur, not uniformly along the line, but sporadically as the irregularities of the fracture, pressure, and nature of the rock have determined. If there is hydrostatic pressure then we can account for this by the descent of a

portion of the earth's crust, and in mass dynamic conditions there would be melting below the segment as well as in the line of faulting, hence material would be squeezed up those spaces along the fracture which had been melted by the friction.

As a rule the concentric arrangement of the areole of contact metamorphism may be better explained on the assumption that the melted mass in an area of pressure added to that pressure by expansion due to the heat. Then with vigorous circulation of hot water with its high potency as a solvent agent, under such conditions, new minerals became formed out of the rock substance with their long axes parallel to the central mass of granite ; new minerals, such as felspar, migrating from the granite into the sediments, would naturally crystallise in the planes of foliation and increase the effect. At the junctions we frequently find that the granite and sedimentary rocks become intermingled in such a way that it is impossible to say where the one ends and the other begins. There are thin laminæ of granite substance bedded in between the metamorphosed sediments ; this is usually taken to be the actual incursion of thin sheets of molten granite between the foliæ of the schists, the *lit par lit* injection of French authors. It may, however, equally be that the sediments are actually changing into granite in the ultimate expression of metamorphism ; vigorous interchange of material by solvent water is going on between the granite and the sediment, and just such layers, which, by reason of their nature, the pressure and the temperature existing in them, are susceptible to the extreme or lesser degree of metamorphism, so they change wholly to granite or alter into schist.

The point I wish to establish, however, is that an ascending granite boss cannot be conceived as a great mass of white-hot material fizzling among the sediments. The temperature of the melting point of granite is above the dissociation point of water, and on every granite contact we have, not baking and scorching of sediments, but alteration by means of

solvent water. It seems, therefore, that the granite has not been intruded as a highly heated material, but one which is liquid owing to other causes, pressure and the agency of solvent liquid water. The whole argument we used for the folding of rocks showed that these were bent as a viscid liquid under great pressure but at no great temperature, and the same agencies are at work in the Archæan, deeply buried sediments ; we can obtain liquidity without immense heat.

In every direction we work we find our evidences for a hot interior of the earth to be swept away.

There is one further point in regard to granite bosses ; that is, the presence of basic selvages. On the theory of melting by heat these can be explained by the fact that the lower the melting point of a rock the longer it remains liquid ; therefore, with a granite with a certain amount of basic silicates fused in it, the latter will remain still liquid when the main bulk begins to solidify, hence it will be squeezed out towards the periphery. There is nothing to suggest such a theory in actual granite areas ; the rock just forms crystals of such minerals as happen to be represented in the liquid magma at such a spot. There is no selective squeezing out of unsuitable material. Segregation bands and patches, when examined in their field relationship, suggest the inclusion and more or less absorption of foreign rocks in the granite, rather than migration of special minerals to a definite patch or zone. I must confess, however, I have only South African examples to guide me.

In the Bushveld granite north of Pretoria there is an immense area of the so-called red granite bordered by a margin consisting of norite and gabbro ; the basicity rises to such an extent that large masses of magnetite separate out, which are of such a nature that the whole rock attracts the hammer and will cause it to adhere as one strikes it. The magnetite is rich in titanium and chromite, while traces of platinum are also present in some localities. In the old granite bosses intruded in slates of the Swaziland system the selvage is a normal one, but this granite was later than the

ferruginous quartzites and dolomites of the Transvaal formation. It is only where the granite impinges on these that the ultra-basic selvage makes its appearance; where it is intrusive in the Waterberg sandstone, for instance, there is no sign of the high iron and magnesian content. The facts, therefore, are extremely suggestive that the nature of the rock encountered by the granite determines the nature of the rock whether it is to be basic or acid. As, however, the theory of magmatic segregation breaks down when applied to these basic selvages, if we suppose it proven that the iron and magnesia were absorbed from the rocks at the contact, so the theory of melting under pressure with solvent water without great heat gains support from them. Had the rock been really molten by heat, then the addition of such a powerful flux as iron and magnesia would have rendered the whole margin especially liquid ; the material inside would be still liquid, being acid rock with a high melting point, so there would be a strong tendency for a fusion of the new material with the acid magma, and the general average basicity of the rock would have been raised, but no segregation could have occurred. On the other hand with incorporation of the magnesia and iron, under pressure and with solvent water at a comparatively low temperature, the liquefaction would be local and concentration of the products would be possible, being directly conditioned by the nature of the rock incorporated at the particular spots.

CHAPTER XVII

SUMMARY

THE universe is conceived to be a self-contained swarm of stellar bodies suspended in vacant space. The stars are either bright, luminous spheres, such as we see in the sky at night, or are dark bodies whose presence can only be inferred, for they have never been seen. These are all journeying along definite paths, some one way, some another, but usually in trains. In course of time certain of them approach near enough for the attraction of their mass to exert a disruptive effect on one or both of the bodies ; the velocity with which they are travelling is sufficient to counteract the attraction of each other as a whole, so that, after approach, the two bodies separate and keep their individual identities. If the approach has been near enough, the smaller of the two will have its substance drawn out into prominences both towards and away from the disturbing sphere on the principle of the tidal phenomena. The original body is supposed to be cold and solid, hence these prominences will consist of rock substance disrupted from the sphere, and they will be drawn out spirally round a central nucleus.

Our solar system is supposed to have originated in this way. Some celestial sphere larger than the original sun came within, say, a distance equal to that between the earth and the sun. On the earth at the present day the sun's attraction causes a bulge or raised meniscus to form on the side turned towards the sun and away from the sun, and if the sun were fifty times as large and of equal density, then the attraction would cause prominences of solid rock to rise from the earth and follow it in its course. The solar system is conceived to

have been a solid, cold sphere similar to the earth at the present time when the disturbing body approached it, and hence solid prominences of rock substance were formed spirally round the primitive sun.

After the departure of the disturbing star, the solid rock substance of the prominences was left to aggregate accordingly as the mutual attractions existing between the fragments and the individual rates of travel and courses of these allowed. Gradually certain patches in the spiral became larger, and as they grew they exerted a preponderating attraction on the scattered material within their orbit; this was in course of time gradually swept up and incorporated in these patches or knots. The latter became eventually the planets; the original nucleus the sun.

The scattered rock substance of the prominences of the primitive sun fell at first in a continuous shower, rendering the surface of the planets and the sun incandescent from the heat of the arrested flight of the infalling bodies; the sun is still in this condition. But the smaller bodies, the planets, arrived at a state in which the bulk of the material became exhausted and the infalling of large masses of the disrupted material became slower and slower, till on the earth at the present day the larger masses do not fall. The so-called dark moon, Eros, however, is such a body out of which the earth was made, and some day that will fall upon the earth. The scattered small lumps are still falling upon the earth as meteorites, some million or more of which fall every twenty-four hours. But the greater number of them are too small to enable them to reach the surface of the earth, being burned up by friction with the oxygenated atmosphere. Some do fall upon the surface, however, having a bulk from 50 tons downwards. From an examination of these meteorites we can arrive at an estimate of the general nature and composition of the larger masses which built up the earth in the beginning.

Meteorites are divided into two classes—iron meteorites composed of nickel-iron, and stony meteorites composed of

silicates of iron, magnesium, calcium, sodium, and other metals. The density of the earth is 5.5; that of iron 7.7, and that of silica 2.6; taking the bulk of the bases on the earth to be iron and the bulk of the acids silica, then the earth as a whole is composed of about six parts of iron and four parts of silica. The original silica was all combined with the bases to form olivine, enstatite, felspar, and similar minerals such as occur in ultra-basic rocks.

Besides the essential constituents of the meteorites there are occluded in the fragmental masses, gases consisting of nitrogen, carbon monoxide and dioxide, hydrogen, marsh gas, and olefines; these formed the primitive atmosphere. Owing to the absence of free oxygen, the earth originally grew up as a mass of unaltered basic silicate and metallic nickel-iron in the proportion of 4 to 6. As long as the arrival of meteoric matter was fairly continuous, the surface of the earth was kept at a high temperature from the impact of the bolides, but the heat was rapidly dissipated owing to the intense cold of the outer space; the central portion, except for distortional movements due to the attraction of the sun, became cold. The iron in the outer edge, however, absorbed carbon from the atmosphere in the same manner as cast iron absorbs it from the gases in a furnace, and a certain amount of the oxygen was liberated. This instantly united with the free hydrogen of the primitive atmosphere to form water, which, however, was not allowed to settle till later, when the surface of the earth became cool enough.

Eventually the arrival of new material on the earth became so slow that the surface was enabled to cool down with the central mass, and water became precipitated and filled the primitive hollows as oceans. At this time lowly organisms were developed whose function was to absorb carbon dioxide and set free oxygen. These were the bacteria, fungi, algæ, myxomycetes and similar microscopic plants and animals which we find to-day dwelling in the soil. These organisms still are able to live under conditions that would prove fatal to all other living beings, both plants and animals,

such as in mephitic atmospheres, without light and even in boiling water; they thus allow us to form some conception of the conditions upon the earth at the time when life was first generated upon it.

We can learn from the surface of the moon the condition of the earth's surface at this period of its existence, because an atmosphere without oxygen and without water is as good as none at all, as far as alteration of the surface features is concerned. Weathering to a certain extent went on, because there was alternate heating and cooling due to the change from day to night, but there was no means for the transport of the weathered material except winds, which are not very effective when compared with water as an agent of transport.

The moon's surface shows us vast craters up which lava came welling, but unlike the present-day terrestrial volcanoes, the lava seldom if ever flowed from the craters. These may be regarded as due to the uprush of material which had been melted by pressure and friction along zones of crushing, but which, owing to the absence of water, exerted no explosive activity; hence the material rose according to hydrostatic pressure, and sunk again on the dissipation of the heat and consequent cooling and shrinking of the mass. Besides the craters there are the great *Maria* of the moon, the Mare Serenitatis, Mare Tranquilitatis, Mare or Oceanus Procellarum, Mare Imbrium, and so forth. Shaler has shown evidence for believing that these are due to the impact of bolides, which, melting up the superficial area of the moon, flooded it with lava derived from outside. We have seen reason to compare areas occupied by vesicular lava and agglomerate in the Archæan rocks with such *Maria* of the moon.

With the advent of water everything changed. The rocks exposed on the surface of the earth not only crumbled by alternate heating and cooling, but their substance became disintegrated. At first the iron-magnesium silicates, olivine, enstatite, and so forth, yielded to the solvent action of the water, and as carbonates of iron and magnesium were carried

away in solution, together with colloidal silica. The small amount of felspar yielded a little hydrated aluminium silicate or kaolin for the rivers to carry away and deposit as mud, but the rest of the substances, the lime, soda, potash, and so forth, were all carried away in solution.

Now commenced a very remarkable action which we can still trace as going on to-day. The iron and magnesium salts did not travel outwards equally with the compounds of lime, soda, potash, and so forth, but were in part attracted towards the centre of the earth. We find still that scarcely any iron, weathered and dissolved out of rocks, reaches the sea, while, although a little magnesium does enter the sea, the larger portion derived from the weathering of rocks descends and alters the limestones buried in the earth to dolomites. This action has been going on continuously, resulting in a progressive impoverishment of the surface of the earth in iron and magnesium, and a concentration of the other elements in the primordial earth-substance, namely, silica, alumina, lime, soda, and potash, among the essentials. The action we ascribe in the case of iron to the attraction of the magnetic nucleus of iron upon the salts of iron when dissolved in water; the molecule of the iron salt is dissociated in weak solutions, and the iron, held by loose bonds to the other elements of the compound, is in the metallic state, and as such can be attracted. Nickel obeys the same laws and has practically disappeared from the earth's surface except in areas where the rocks have all the appearance of being great meteorites which have been crushed and folded into the earth's crust, but which are otherwise unaltered. Why magnesium descends into the earth's crust instead of travelling outwards like the other elements such as lime, soda, and the elements generally which we find in sea water, is still a mystery; we can only note the fact that the magnesium dissolved out of rocks by the processes of weathering does descend.

The silica dissolved out of the primordial silicates would probably have been carried away to the sea in solution.

We must remember that the water of the original rain was highly charged with carbon dioxide, and the pressure of the atmosphere was in all probability greater than it is now, since we know that a vast amount of the original atmosphere has been fixed in compounds in the rocks of the earth's crust. From both these causes, greater acidity and greater pressure, the solvent action of the water as it was precipitated from the clouds in the beginning of geological history was very much greater than it is at the present time.

At any rate siliceous sediments began to grow in the sea at first as deposits of chalcedony or chert. The rest of the products of weathering, except for a little mud, also entered the sea in solution. The primitive ocean, therefore, was a strong solution of iron, magnesium, and lime salts with dissolved silica, and a small fraction of those salts which are at present dissolved in sea water. Deposition might have been by organic agency; we know nothing of what might have been the primitive organisms in the sea. Possibly the earliest sea animals and plants were the radiolaria and diatoms; the extraordinary beauty and complexity of their forms suggest that they have had a longer total existence as a class than other organisms. Whether the silica was deposited by organic agency or simply from supersaturation does not materially matter. Siliceous deposits were formed and the deposit was not crystalline; there was no quartz yet upon the earth.

In due course the pull of the sun upon the earth's prominent features, the continents, caused these to slowly creep from east to west, and eventually what were primitive continents became oceans and the primitive oceans became land. The deposits on the ocean floor were laid dry. Now for the first time silica rocks were exposed to denudation, and as a result the first sands became separated and carried down by the rivers into the sea; they consisted, however, not of quartz grains but of chips and splinters of chert or uncrystallised silica.

In due course the sediments accumulated, till after a while

sufficient were piled one on top of the other for the agencies of metamorphism to act. The water percolating through the interstices of the rock where it came into the deeper parts, under pressure, dissolved the chert fragments, the aluminium silicates and limestones of the primitive sediments, and re-crystallised the constituent substances; the process is the same as in Barus's experiments, where the glass was dissolved by water in capillary tubes under pressure and deposited in the form of crystalline silicates. Thus for the first time rocks with crystalline silica or quartz became formed on the earth's surface.

We follow, then, these processes of weathering of the earth's surface, from the time when it consisted practically entirely of iron-magnesium silicates and metallic iron, through stages in which the primitive surface becomes covered with sediments containing less and less iron and magnesium, but more and more of silica and of the less common elements in meteorites —calcium, sodium, potassium, carbon, sulphur, phosphorus, and so on.

At first, when the substances weathered out of the rocks of the continental areas went into solution, the continents were relieved of pressure and could therefore rise, but the matter carried away was distributed over the whole sea floor; afterwards, when the rivers carried more mechanical products of weathering, sand and mud, these became deposited along the shores of the continents, which then became subjected to concentrated loads. Consequently in the beginning the change from land to water was occasioned only by the secular creep under the pull of the sun's attraction, and the oscillation of land surface and ocean floor was slow. With the increase in bulk of the mechanical land-detritus the oscillation became more rapid. Hence we find enormous gaps between the successive systems in the Archæan rocks, but the unconformities between the two systems in the Mesozoic are shorter than those in the Palæozoic, and in the Cainozoic than in the Mesozoic eras. In the older series of rocks, again, a single kind of sediment may continue monotonously to persist for

many hundreds or even thousands of feet of vertical depth, whereas in the later series there is a much more general tendency towards frequent alternations of different kinds of sedimentary material: sandstones, shales, and limestones succeed each other in rapid interchange.

The period during which the first chalcedonic silica sediments were laid down is the beginning of the geological history of the earth; before then we count the earth as being in an astral condition. This period is lost among the granites at the base of the earth's crust. Ever since then the rocks of the earth's crust have been becoming more and more siliceous, but this action has been brought about, not by simple abstraction of the iron and magnesium, but by the successive disintegration of rocks on the land, the deposit of the detritus, and precipitation of the dissolved substances in the ocean, the elevation of these sediments into dry land, and a recommencement of the cycle over and over again.

This has progressed till the whole mass so worked over on the surface of the globe amounts to a thickness of 30 miles. We know that the rock at the bottom of the 30 miles must be of the same physical nature as that at a mile or so from the surface, because earthquake waves are transmitted with the same velocity through chords of the earth's surface at the same rate as long as these do not penetrate more than the 30 miles. That is to say, the rock must be siliceous, solid, and crystalline, and one containing water in its capillary and sub-capillary interspaces. It is a granite or of granitoid nature, because we find that under pressure the normal sediments, no matter how diverse they may be originally, pass by interchange of material in solution into the state of a gneiss, that is a rock consisting essentially of quartz, felspar, and an iron-magnesium silicate, foliated normal to the direction of pressure. Under extreme pressures, such as exist 20 or 30 miles down in the earth's crust, water is a powerful solvent, and rocks are ready, by reason of the water held up in their capillary and sub-capillary interspaces, at any increase of pressure, or under differential movements, to pass into a state of solution, that is, to become

practically liquid, though cold. Hence normal sediments at a great depth in the earth's crust will be in the condition of a liquid, and will, therefore, transmit pressure equally in all directions; the rock then crystallised will consequently not be a foliated gneiss, but an irregularly grained granite.

The conception of the internal heat of the earth has been arrived at, because the farther we go down in the earth's crust the hotter the rocks become. The average increase is 1° F. for every 60 feet. When we estimate the increase in granite or Archæan rocks, the increase becomes as slow as 1° F. for every 200 feet. There is every evidence that we are entering a colder region than the more external layers of the earth. When we take the readings from a single deep boring or shaft we see that the increase of temperature is not in any way constant, but is conditioned solely by the nature of the rock encountered.

We know, further, that the lower layer of the crust is not intensely hot, because the physical condition of the rock there, as estimated by the rate of transmission of earthquake waves, is the same as that a mile or so down from the surface. This necessitates the presence of water as water, not as vapour, in the interstices of solid rock-grains.

The heat of the earth's crust we ascribe to the presence of radio-active substances, which, if estimated at radium alone and existing generally only in quantities such as rocks poor in radium indicate, would require an envelope of 45 miles of rock-containing radium. If the radium content of the crust be estimated a little higher, an envelope 20 or 30 miles would be sufficient. But besides radium, there are the continual movements in the earth's crust, caused by the weighting of the crust by sediments and the lightening of continental regions by the carrying away of rock-waste; these differential movements cause the segments of the earth's crust to move and to rub one against the other, and consequently heat is developed. These, again, set earthquakes vibrating through the earth, and the energy of a dislocation is transmitted throughout the earth's crust and is absorbed by it.

The folding of mountains is ascribed to the breaking of continual earthquake waves upon certain segments of the earth more opaque to them than others. The sea floor, deeply burdened with sediments, transmits earthquake waves with a speed compared with that in the granite bases of 5 to 3 for compressional waves, and 3 to 2 for distortional waves. Hence the waves drag as they come from the area of the oceans to the land and the waves of vibration are converted into waves of translation; the sediments of the sea floor are driven towards the land in a way similar to that by which the top surface of the ocean water is driven landwards, owing to the interruption of the waves on the shelving shore.

Rocks are folded cold, and no temperatures anything approaching the melting points of silica are requisite in bending into the most complicated folds even such a refractory rock as a quartzite. The movements of folding are accomplished by the solvent action of water, which becomes extremely active under pressure, given sufficient time. In laboratory experiments a high temperature is necessary to observe this effect, but in nature, with unlimited time for the accomplishment of results, the solution and redeposition of silica and silicates, whereby a rock is enabled to accommodate itself to stresses, goes on at a temperature very little higher than those obtained at the bottom of deep mines. In fact rocks have been known to bend at the bottom of deep mines when the supports in the levels and drives have been removed, and the bottom of a deep bore-hole will slowly rise as a plug when the boring-rods are removed.

The reasons for the postulation of a hot interior of the globe are then: firstly, the supposed origin of the earth from a gaseous and liquid sphere under the Kant-Laplacian hypothesis; secondly, the increase of temperature as one descends into the earth; and, thirdly, the molten condition in which rocks deeply buried have apparently been. None of these bear scrutiny; the phenomena observed can far more reasonably be explained on the assumption of a cold interior of the earth, and that is the logical conclusion consequent

on adopting the planetismal hypothesis of Prof. T. C. Chamberlin in its ultimate form, and it accords more with the deductions of G. K. Gilbert and O. C. Farrington from their observations respectively of the moon's surface and the composition of meteorites.

The centre of the earth consists of unaltered iron-magnesium silicate with iron, because, when water is drawn by capillary and molecular attraction from the surface of the globe, and when it reaches the unoxidised and dehydrated centrosphere, the latter takes up this water into combination; consequently the rocks swell and close up the minute sub-capillary interspaces and thus bar the way for further intersusception of water.

That the centrosphere is practically identical with the average composition of meteorites we see in the diamondiferous volcanic pipes drilled through the crust, where it has been whittled away by excessive and long-continued denudation. There these pipes actually dip down into the centrosphere and bring up through their chimneys masses of rock which have long been known to be of the same constitution as meteorites, so much so that at one time it was thought that these diamond pipes were actually large meteorites which had fallen and had embedded themselves in the earth. That they are not so is proved by dykes of unaltered blue ground which traverse the rocks like ordinary igneous dykes. Africa has been bulged by the expansion of the nucleus of the earth owing to the relief of pressure consequent on this removal of sediments from on top, so that Africa at the present time exists as a rounded knob on the earth like the stalk end of a pear. The existence of escapes of this centrospheral matter in Australia as diamond pipes, or in Greenland, where the matter is metallic iron intermingled with basic silicates, is explained in the theory of the development of pressure zones greater than ordinary ones, which have penetrated down below the siliceous crust into the centrosphere. The presence of mountains of ultra-basic materials, especially in New Caledonia and the Urals, may be due to the same cause, or they may be explained by the theory that they are actually large meteorites

which have been rolled and folded in with the earth's rocks owing to movements subsequent to their fall. It is significant that the conglomerates bearing diamonds, presumably originally formed in ultra-basic rocks as in the Kimberley mines, such as we find in India, are Cambrian, and therefore were formed when the earth's siliceous crust was thinner than at present.

Volcanoes are readily accounted for on the assumption of a cold globe, for it is found that earth-movements in a vertical direction are accompanied by crush-breccias where the rocks are infusible quartzites, or are not sufficiently buried. Where the rocks are calcareous or ferruginous, or are deeply buried, then the pressure and friction along the zones of movement are sufficient to raise the temperature above the melting point and the rocks are fused. As all rocks down to the centrosphere contain water in the capillary and sub-capillary interspaces, the fusion of rocks means the development of steam under immense pressure. Hence, when melting sets in, there are explosions beneath the crust which eventually shatter the rock on the line of movement, and these cause channels to be drilled to the surface. Up these chimneys comes the molten rock to form volcanoes. If the rock had always been molten and had been kept in that condition in a subterranean reservoir, then the intense shattering that we find along fault lines ought to have let out the molten rock from below. Not only is this not so, but many volcanic pipes in Swabia, Scotland, and South Africa, which we know go very deep down into the earth's crust—for they are filled with the shattered rocks existing at enormous depths below the surface—have not brought up molten lava, but others near by may have done so. Two pipes dipping equally into the supposed molten magma beneath the crust ought both to be filled with lava, but as they are not in the countries mentioned, we have to suppose that the presence or absence of molten rock is dependent on the rocks through which the pipes are drilled; if they are fusible then there will be lava, if infusible, then there will be only explosion tuffs.

The presence or absence of ultra-basic selvages to granite bosses bears out this contention; for where these impinge on quartzites the border is acid, but where the rock at the surface has been charged with iron and magnesium, then the ultra-basic selvage is formed.

The earth's crust is held to be uniform throughout. From the universal presence of granite in the basement below the sediments and crystalline schists, it is taken that this is the fundamental rock of the earth's crust. All the surface features that we see, the hills of quartzites, the plateaux of limestone, the valleys of slate, are all accidents of the extreme surface. When in course of time these become buried, the limestone gives to the quartzite and slate, and the quartzite gives to the slate and limestone, and the slate gives to the limestone and quartzite their essential constituents through the medium of solvent water circulating in the capillary and sub-capillary interspaces under pressure. These rocks, separated out originally from granite, are reconverted by the action of metamorphism into granite, and the cycle is a recurring one.

Throughout the processes of denudation and deposition the iron, and to a less extent magnesium, descends into the earth and travels towards the centre. The granite beneath receives these but it does not hold them; indeed, what is left of the iron and magnesium in the granite itself is subject to be called upon to yield to this ever-present magnetic attraction, but under mass static conditions the diffusion of substances is slow, whereas at the surface molecular activities are vigorous, and alteration is always at work.

The existence of continents is due primarily to irregularities on the surface of the globe caused by the infalling of large meteorites; then when water became precipitated and denudation started, the relief of load by the decay of the rocks and the transport of the waste to the sea caused blocks to rise; these blocks became the primordial continents. Once sediments formed along their shores, new forces came into play and folding of mountain chains became possible; but

the continual pull of the sun as the earth revolved caused a secular creep of these land-masses, so that in course of geological time the whole globe has been alternately land and sea. This secular creep was, in the beginning, the most potent agent in altering the surface features of the globe, and the ridges followed each other round and round. These ridges are still visible, at least five of them are: the Australo-Chinese line, the Indian line, the African line, the Mid-Atlantic line, and the American line; the sixth lies foundered beneath the waters of the Pacific. But in the later geological history of the globe, from the Cambrian upwards, folding has been superimposed on these remnants of the Astral period, and in the lapse of time represented by the deposition of the fossiliferous rocks, this folding has gone on at such a rapid, and, ever increasingly rapid, rate, that it has almost obscured the main ridges.

The assumption of an earth-crust of equal density throughout the continents and ocean basins necessitates the postulation of a concave surface for the water of the oceans. The water is drawn up along the shores of the continents by the attraction of the outstanding masses. Hence, although movement of land-masses in an upward direction, and ocean-basins in a downward direction, does actually happen, yet the elevation of a continent may be exaggerated by the fact that not only does it rise by the relief of pressure, but the clearing away of the rock from the surface also diminishes the attraction of the continent on the sea and, therefore, the sea retreats.

The sinking of an ocean-basin takes place along the edges by means of the loading of these by the deposition of sediment; the surface of the ocean-floor, therefore, would become markedly convex. Earthquake-waves, however, breaking along the borders of the continents tend to draw away material from the centre of the ocean area and pile it up along the shores; hence there will be two opposing factors which will keep the ocean-floor normally level. Along the line of the shore, therefore, we have movement in a vertical direction, and pressure. Under certain conditions this latter

is converted into heat, and volcanoes are formed, as, for instance, round the Pacific; or the pressure accumulates without frictional heat, and folded mountain ranges are formed as in the case of the Alleghanies.

The land encroaches upon the ocean by elevation of the deposits by folding. But there is apparently also some method by which the whole area of the ocean can be raised in the same manner as a whole continent can be, and conversely a continent can be depressed as an ocean-basin can be. Secular creep will do this, but there has gone on a process of elevation and depression more rapid than can be accounted for by this. An ocean-basin we can think of as a vast pit let down in a similar way as the fault-pits of Steinheim and Baviaan's Kloof are. Then, as in the Rocky Mountains, blocks of the crust are elevated relatively by the sinking of the earth round them, by faults or steep folds. The rising of an ocean-basin by the sinking of the continents round it would be an analogous case, but, though these movements have gone on, it is impossible to understand the processes by which they have been brought about.

In conclusion, although we have in this book dealt with almost all the large problems in geology, we have in no one case found that the explanation of the cause for the production of the phenomena could be helped in any way by the assumption of a hot interior of the globe. The facts observed in the field or recorded observations explain, without bringing in any unknown factors, the whole of the causes which produced them, if they are allowed to range themselves in proper order. In no one case have we called in the aid of pure speculation, such as the nebular hypothesis. In all cases we have endeavoured to arrive at our explanations in the simplest possible way; thus, if meteorites do fall on the earth, it is surely legitimate to take them as average samples of the interstellar matter out of which our earth has grown. Then, when we find that when the volcanic pipes dip sufficiently deep in the earth the same material comes up to the surface, there is enough proof to

establish the definite conclusion that the earth's interior must be unaltered meteoric material. If I may use an illustration from the history of literature, the present work constitutes an appeal for a return to rationalism after a period of romanticism. I use these terms in the sense in which they are applied in literary criticism. I do not mean that the theoretical enigmas with which geology is burdened at the present time are pure romance, but that the dominant factor has been theoretical conceptions which have had no basis in fact, and that the fundamental theories of modern geology stand in the same relation to logical deduction from facts as romanticism stands to rationalism in the domain of literature.

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